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Variation in the Life History of the American Smelt in Inland Waters of Maine

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ABSTRACT

A survey conducted by Wardens of the Department of Inland Fisheries and Game provided information on the time and duration of smelt spawning runs in 114 Maine lakes in 1958, and in two lakes in years prior to 1958. Other phases of the Maine smelt investigation provided information on spawning sites, habitats occupied, maximum sizes, and behavior with respect to angling. Large variations in these aspects of the life history of the smelt were found.

Evidence is presented which suggests that certain phases of the spawning behavior are subject to the law of heterogenous stimulus summation. Possible reasons for the different habitat types occupied, the different maximum sizes attained, and the differences in behavior with respect to angling are briefly discussed. It is suggested that these variations might be the result of speciation in progress. If so, the genetic constitution of the various smelt populations might have implications in management.

INTRODUCTION

Freshwater populations of the American melt, *Osmerus mordax* (Mitchill), are nown from lakes of New England, New ork, eastern Canada, and the Great Lakes gion. Freshwater smelts are widely distribud in Maine and are considered a particular- important component of the native fish una because of their varied ecological relanships with valuable game species. They e also important as sport, bait, and food shes. Investigations into the life history and ology of this species are under way in Maine that management may be placed on a more tional basis.

One of the most striking features of the elt in Maine is the variation it displays in ny phases of its biology. This variation y be found both within habitats and between habitats. Known variations are:

1. Time, duration, continuity, and site of spawning;
2. Physical and faunal characteristics of waters inhabited;
3. Maximum size attained;
4. Behavior with respect to angling.

This paper describes the extent of variation of these features for smelt populations located in lakes throughout Maine and discusses some of the implications of these variations with respect to behavior and speciation.

VARIATION IN TIME AND DURATION OF THE SPAWNING PERIOD

Variation between lakes

Most general works on the life histories of fishes state simply that freshwater smelts spawn in tributary streams in late winter or early

spring. Authors writing specifically on smelts have been more definite. Langlois (1935), at Crystal Lake, Michigan, and Hoover (1936), at Winnesquam Lake, New Hampshire, found that the smelt runs began at the time the ice disappeared from the surface of the lake. Creaser (1926) observed smelts spawning slightly before ice-out. Kendall (1927) recognized variation in the time of the smelt runs and included a table giving spawning dates for 16 Maine lakes, the dates ranging from February through May. Van Oosten[1] also recognized variation in time of smelt spawning and stated that Great Lakes smelt runs may " . . . . begin as early as March 17 and as late as April 28 and end as early as March 31 and as late as May 7, the time of the run depending on weather conditions, particularly temperature, and possibly other factors". Marcotte and Tremblay (1948) considered the variation in date of spawning of marine smelts along the Atlantic coast of North America and concluded that it was related to the temperature of the sea; spawning usually begins at temperatures from 39°F. to 42°F. Factors other than temperature and date have not heretofore been discussed in detail.

The popularity of dip-netting smelts on their spawning runs in Maine makes it necessary for the Maine Warden Service to patrol smelt brooks intensively during the spawning season. During the 1958 season, Wardens were provided with forms and instruction sheets requesting them to make a record of the beginning and ending dates of the smelt runs in their district, the date of ice-out for each smelt lake in their district, the size of the smelts participating, and related information.

Partial results of this survey, presented in Figure 1, show the beginning, duration, and end of the smelt runs in 114 lakes in relation to the most significant climatological change of the early spring, the break-up of the ice cover. Also indicated in Figure 1 are median dates of ice-out for each of the 10 Warden Service Divisions reporting. The Divisions are arranged in order by date from the earliest ice-out in Division B to the latest ice-out in Division K. The resulting order nicely reflects the later ice-out dates in the Divisions located in the more northern and inland portions of the

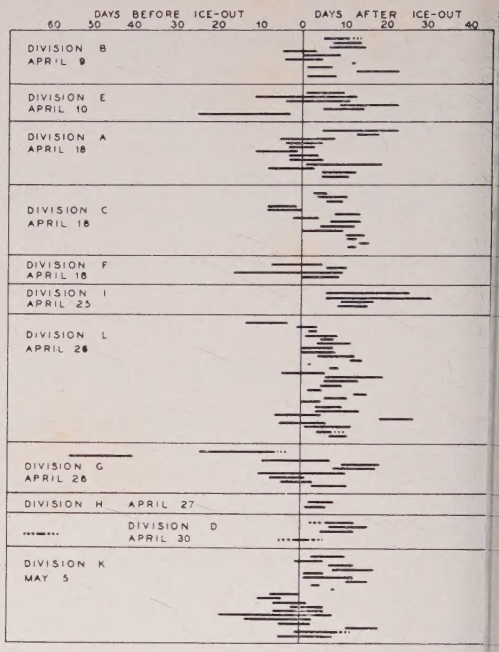

FIGURE 1. Time and duration of smelt runs 114 Maine lakes during the season of 1958. T horizontal lines represent the beginning, duratic and end of each run with respect to the date of i out for each lake represented. Dotted segments the lines indicate uncertain beginning or endi dates. The Warden Service Divisions which ported these data are arranged according to advar ing median date of ice-out for the Division. Nan and locations of the lakes can be furnished on quest.

State. Ice-out occurs first in the southern a coastal sections. Warden Service Divisions a administrative segments of the Warden Bran of the Department of Inland Fisheries a Game.

It is evident from Figure 1 that there is significant relationship between the time most of the smelt runs and the time of ice-o The numbers and percentages of runs in pr ress at various times relative to ice-out may summed as follows:

Days before or after ice-out	Number of runs in progress	Percentage runs obser
20 or more days before	4	3.5
15 days before	4	3.5
10 days before	10	8.9
5 days before	25	21.8
Days of ice-out	38	33.2
5 days after	57	50.0
10 days after	45	39.4
15 days after	21	18.4
20 days after	7	6.1
25 days after	3	2.5

[1]Van Oosten, John, 1940. The smelt, *Osmerus mordax* (Mitchill). Mimeo. Rept., Mich. Dept. Cons., Lansing, Mich., Rev. 1948, 13 pp.

The arrangement of frequencies provided by this summation strongly suggests a normal distribution with mode at 5 days after ice-out. Ninety-one of the 114 runs (80 percent) were in progress within the first 10 days after ice-out.

There appears to be no relationship between the time of the smelt runs and calendar date. This can best be shown by arranging the beginning dates of the runs in a histogram as in Figure 2. This Figure shows most runs beginning between April 9 and May 5, the extreme median dates of ice-out, but does not show any marked peak for any particular date or period within this interval. Figure 2 also indicates the lunar cycle which is apparently no more related to the timing of the smelt runs than is date.

Both figures show large deviation in the timing of several of the runs. Extremes in days relative to ice-out were:

Beginning of run	early - 55 days before ice-out
	late - 19 days after ice-out
End of run	early - 40 days before ice-out
	late - 31 days after ice-out

Extreme differences in date were:

Beginning of run	early - February 23
	late - May 16
End of run	early - March 9
	late - May 25

Of the 114 runs studied, 10 took place wholly before ice-out, 31 included the date of ice-out, and 73 took place wholly after ice-out.

Duration of the runs was variable also. Average duration was about 10 days. The longest run lasted 28 days and the shortest was completed in one night. Durations of the runs showed no relation to calendar date or date of ice-out.

Most authors discussing smelt biology have attempted to show a relationship between initiation of spawning and stream temperature. The average temperature cited lies generally in the range 40°F. to 45°F. Marcotte and Tremblay (1948) have sensibly pointed out, however, that maturation of the gonads and initiation of the spawning migration take place in the waters inhabited by the adults rather than in the streams in which they spawn, and that the factors which release the spawning complex should be sought offshore. These authors presented data showing initiation of spawning of marine smelts at sea temperatures of 39°F. to 42°F.

While direct observations on water temperatures were not taken during this survey, some information is available and some can be deduced. The temperature of the water immediately under the ice of lakes in winter is very close to 32°F., while the warmer bottom layer usually begins several feet down. This inverse temperature stratification normally persists until approximately the time of ice-out since the winter heat-gain from solar radiation through the ice is very small (Welch, 1952). After the ice melts, the winter stratification is destroyed and general warming of the lake begins. This is a general physical phenomenon typical of temperate lakes of the second order which form a winter ice cover, and it cannot be expected to vary except in localized situations where large springs or rivers may exert

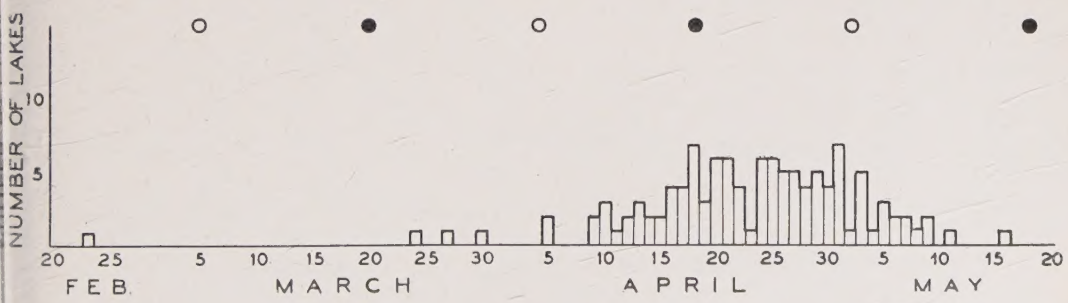

Figure 2. Beginning dates of smelt runs in Maine in 1958. Open circles indicate dates of full moon; darkened circles indicate new moon.

their influence. An illustration of the early spring temperature changes in such a lake is presented in Figure 3 which was prepared from data collected at Branch Lake, Hancock County, Maine, during the spring of 1957. Similar data from other areas and other years confirm that this temperature regime is typical of most Maine lakes in early spring.

The logic of Marcotte and Tremblay's (1948) observation that initiation of reproductive behavior in smelts must take place in the pre-spawning environment of the adult is certainly as applicable to lakes as it is to the sea. However, the data presented in Figure 1 do not show that temperature alone is very important in this respect in fresh-water lakes. Thirty-five percent of the smelt runs began before the ice had left the lakes and when water temperatures were at their lowest. On the other hand, 12 percent did not begin until 10 or more days after ice-out when temperatures would usually be in the 40's and rising rapidly.

The relationship between smelt spawning runs and stream temperatures is equally variable. In February, 1958, the smelt run at Cold Stream Pond, Penobscot County, took place under heavy ice and snow cover on both lake and stream and with stream temperatures at about 32°F. The 1957 run in a tributary to Branch Lake, Hancock County, began at stream temperatures very close to freezing and continued through sporadic increases to a high of 44°F. Temperatures in this stream were very low on one night, and spawning took place while anchor ice was forming. The 1955 run at East Musquash Lake, Washington County, began at a stream temperature of 42°F. and continued through increases to 46°F. Greene (1930) reported smelts spawning at temperatures as high as 59°F.

We can very reasonably conclude that there is a marked inconsistency in the timing of smelt runs with respect to temperature.

Variation within lakes

The material presented in the foregoing paragraphs results from study of variation between lakes in individual seasons. Year-to-year variation in individual lakes also exists. Figure 4 presents time and duration of smelt runs in single tributaries at Long Lake, Aroostook County, during the years 1943 to 1958; and at Grand Lake, Aroostook County, during five of the years between 1951 and 1958. The scale is the same as that in Figure 1, relating the timing of the runs to date of ice-out. Here, as in Figure 1, there is a general relationship between timing of the runs and date of ice-out, but considerable variation exists. Half of the Long Lake runs began from 1 to 10 days before ice-out and half of them began from 1 to

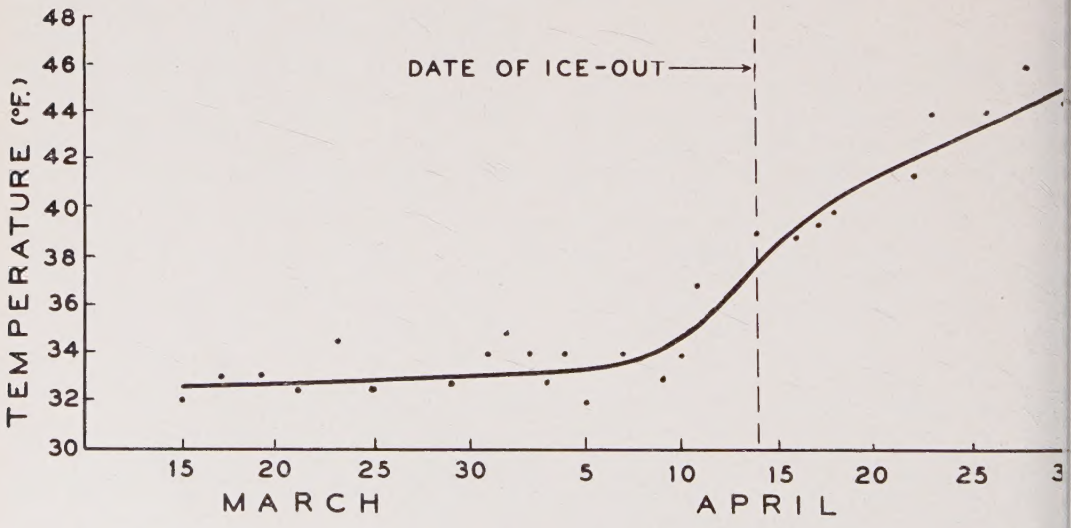

FIGURE 3.—Surface temperatures of Branch Lake, Hancock County, Maine, during March and April 1957. Temperatures were taken through a hole in the ice until April 5. Between April 6 and April 1 temperatures were taken in open water near shore. After April 15, temperatures were taken from a bo well offshore.

15 days after ice-out. All of the Grand Lake runs began before ice-out, preceding that date by 3 to 15 days.

If the Long Lake data are plotted with respect to calendar date rather than with respect to date of ice-out (Figure 5), a different interpretation is suggested. The 16 smelt runs at Long Lake began consistently between May 1 and May 12, but date of ice-out varied from April 23 to May 20. Thus, we have a greater correspondence between calendar date and the beginning of spawning than we do between date of ice-out and the beginning of spawning. However, these data are not necessarily in conflict with the general relationship between initiation of spawning and date of ice-out which was suggested above. The modal date for beginning of spawning at Long Lake was May 8 and the modal date of ice-out was May 7. If this is a real correspondence and if these events have similar or, at least, constant relationships in other lakes, then there is no real inconsistency between analyses based on lake-to-lake and on year-to-year variation. There may be a tendency for smelt spawning to be initiated on or near the modal date of ice-out in many lakes, and, if so, this implies beginning of spawning on some particular calendar date. Since modal dates of ice-out vary from lake to lake, however, the dates of the spawning runs also vary. On a lake-to-lake basis, therefore, we observe a much greater relationship between spawning and ice-out than between spawning and date.

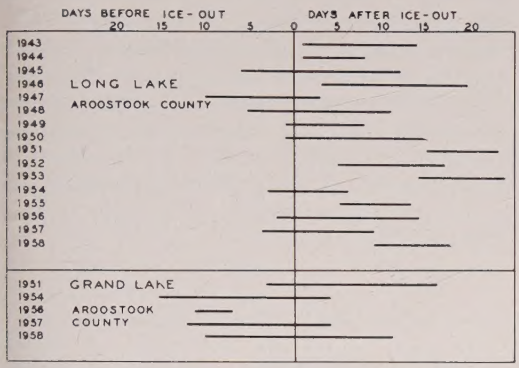

FIGURE 4.—Time and duration of smelt runs in individual tributaries of two Maine lakes in different years. Horizontal lines represent the beginning, duration, and end of each run in relation to the date of ice-out for that year.

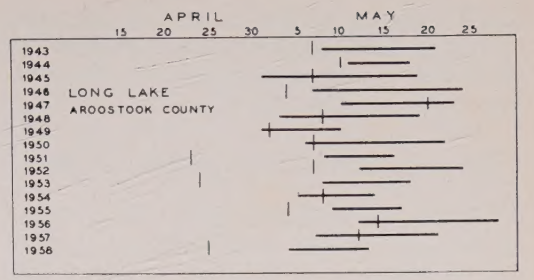

FIGURE 5.—Time and duration of smelt runs in a tributary of Long Lake, Aroostook County, Maine, in different years. Horizontal lines represent the beginning, duration, and end of the runs in relation to calendar date. Vertical marks indicate date of ice-out.

In spite of the general relationship between spawning period and ice-out which has been shown, the marked variation which occurs in some Maine lakes cannot be overlooked. The February spawning run at Cold Stream Pond, Penobscot County, does not begin at all close to the date of ice-out. Duck Lake, Hancock County, has an even earlier run. Smelt runs at Branch Lake, Hancock County, began an average of 9 days before ice-out during eight years for which records were kept. The 1958 run at Howard Pond, Oxford County, began 19 days after ice-out, and it is reported that this was not unusually late.

One other point should be stressed. The Long Lake data indicate a relative constancy in date of smelt spawning (May 1 — May 12 in 16 years) within one lake. If this constancy is typical of most lakes, the state-wide data illustrated in Figure 1 must then provide a fair picture of the total variation exisiting among the 114 lakes represented.

Variation between different spawning areas of a single lake

In addition to variation in date of smelt runs in different lakes in the same year and in the same lake in different years, there is also variation between the dates of runs in different spawning areas of a single lake. At Branch Lake in 1957, the spawning run at Dean Brook began 14 days before the ice left the lake and continued until 10 days after the ice left. At Moore Brook and Black Brook, tributaries to the same lake, however, the runs did not begin until shortly after ice-out, coinciding approximately with the peak of spawning at Dean Brook. Spawning in shore areas also

began several days after ice-out. Further work at Branch Lake in 1958 confirmed these observations; all the runs began later but their time-relationship was the same.

DIURNAL VARIATION IN SPAWNING ACTIVITY

Spawning of freshwater smelts occurs at different times of day. Most published accounts cite the smelt as a night-time spawner, but sportsmen persistently report daytime spawning in some waters. Several authors have discussed these reports, usually expressing doubt as to their accuracy. Kendall (1913, 1927) and Hoover (1936) reported the daytime presence of smelts in spawning streams under various conditions but did not find them spawning. Van Oosten *(op. cit.)* reported daytime runs in certain Michigan streams but did not specifically state that the fish were spawning.

The 1958 Warden Service survey of smelt spawning runs in Maine considered this question. Wardens reported daytime runs in 21 of the 69 lakes from which information was available. Some of the daytime runs were reported to be extremely heavy. While it is possible that actual spawning did not take place in all these cases, daytime spawning has been observed by the author at Cold Stream Pond, Penobscot County, and by an experienced and reliable Warden at East Musquash Lake, Washington County.

There is also variation in time of spawning among smelt populations with the usual night-time spawning habits. The 1957 spawning runs at Branch Lake, Hancock County, began immediately after nightfall on 11 nights, and began one to several hours after nightfall on 7 nights. All runs began by 12:30 a.m. at the latest. These delays appear not to be related to temperature, weather, moonlight, or man-made disturbances.

VARIATION IN OCCURRENCE OF RUNS WITHIN THE SPAWNING PERIOD

Smelts do not necessarily run continuously throughout the spawning period as defined here by the beginning and ending dates. The 1957 run in one of the tributaries to Branch Lake, Hancock County, began on April 1 and lasted until April 24, but there were six nights during this period on which no runs occurred. There is no reason to believe that other runs do not display similar discontinuity.

Two of the six nights on which no smelt runs occurred at Branch Lake were nights of rather heavy sleet or snow storms. Four of the failures were on the first four of a period of five nights during which there was very bright moonlight. The moonilight on the fifth night was equally bright, but a sizable smelt run occurred none-the-less. These observations suggest a possible inhibitory effect of storms and bright moonlight, but they also show that other factors operate here too; the runs are not completely controlled by weather conditions. Man-made disturbances were not involved in these particular failures, although interference by man can prevent the runs under certain circumstances.

VARIATION IN SITE OF SPAWNING

Smelt runs are known from practically all types of natural lotic environment. Runs may occur in the largest rivers and in the smallest temporary brooks. Smelts may spawn in streams entering the lake directly, or they may pass through extensive marshy deadwaters to spawn in areas farther upstream. In some areas they are known to spawn in the deadwater itself. Stream source has no apparent influence; smelts may spawn in lake outlets, streams draining extensive swamps, or in upland streams. Water color seems equally unimportant; smelt runs are known in highly colored waters as well as in clear waters.

Stream substrates acceptable for smelt spawning are also variable. While clean gravel or coarse sand may be preferred, streams that do not provide those substrates are also used (see also Kendall 1913). Eggs have been found deposited on sand, boulders, mud, aquatic vegetation, brush, flooded grasslands, concrete or wood sluicebeds, and on all kinds of debris. One of the heaviest spawning runs at Branch Lake is in a brook which provides only large boulders covered with *Fontinalis* sp.

Freshwater smelts may also spawn on shoals or beaches in lakes (Van Oosten, *op. cit.;* Lievense, 1954; Scott, 1954; Trautman, 1957). Studies in Maine indicate that shore spawning may be considerably more important in the biology of smelts than has previously been recognized. Smelts are known to be present in several Maine lakes that have no inlets, and, thus, lake spawning must be maintaining the population. At Sheepscot Pond, Waldo Coun-

ty, tributaries are available, but they are not used; smelt eggs are deposited on submerged bushes and debris around the shores of the lake. At Branch Lake, smelts do not make use of all the tributaries available, but they do spawn in at least 12 different areas around the shores, some of the areas far from any tributary.

Shore-spawning substrates preferred by the smelts at Branch Lake appear to be the clean sand or fine gravel of natural or artificial beaches; although rubble, coarse gravel, aquatic vegetation, submerged bushes, and debris are also used. Depths range from a few inches to approximately 2 feet. All eggs were found in small patches measuring roughly 10 by 20 feet. No obvious factors distinguished spots on which eggs had been laid from adjacent spots on which eggs had not been laid.

Exploratory investigations into the survival rate of shore-spawned smelt eggs were made at Branch Lake in 1958. Small samples indicated hatching success rates up to approximately 6 percent.

As an indication of possible further variation in spawning habits, the 1958 Warden Service survey reported 94 smelt lakes in which no spawning runs are known. Some of these lakes are remote and the lack of information is not surprising, but many of the lakes are not remote. For example, the time and site of smelt spawning at Moosehead Lake, Piscataquis County, one of Maine's most popular and heavily fished waters, are not known.

THE RELEASING MECHANISM FOR SPAWNING

Recognition of the variation in timing and site of smelt runs leads naturally to speculation about the nature of the stimulus which releases the reproductive behavior. All the evidence presented in the foregoing sections is arrayed against the existence of any single physical event operating in this capacity. The alternative possibility is a combination of factors.

Students of animal behavior have long been aware that many of the mechanisms releasing major behavior patterns are complex and may involve several qualitatively and quantitatively different stimuli. Internal stimuli are equally as important as external ones. Hormone level has been shown to influence gonad development and reproductive behavior in many species. Tinbergen (1951) describes the ". . . mutual relationship between internal and external factors in the sense of an additive influence on the motor response. A high intensity for one factor lowers the threshold for the other factors. A high hormone level increases the responsiveness to external stimulation; if the hormone level is low, very intensive external stimulation is required to bring the total of causal factors above threshold value. It is evident that, while the impulses derived from sensory nerves are qualitatively different from those coming from other sources, their influence on the motor response is added quantitatively." Fabricius (1950) describes this relationship in slightly different words: "The instinctive action is released when the sum of stimuli reaches a certain threshold. The various external simuli stand in a compensatory relation to each other and to the internal stimulus level. This internal stimulus level rises if the instinctive action is not released. What decides the release is only the fact that the stimulus summation reaches the threshold, but it is of no importance *which* of the sign stimuli of the releasing mechanism are included in this summation." This principle is termed the "law of heterogenous stimulus summation".[2]

Observations which confirm the principle of heterogenous stimulus summation have been made with many species. Tinbergen (1951, 1953) has described stimulus summation in the release of several instinctive behavior patterns in sticklebacks and herring gulls. Seitz (1940) showed summation in the mating and fighting of the cichlid *Astatotilapia strigigena*. Fabricius (1950) has shown summation in the release of reproduction in pike, whitefish, and char. In pike, a summation of internal stimuli, rising temperatures, the sight of other pike, and the presence of vegetation are required. In whitefish and char, three of the known stimuli are (1) internal motivation, (2) a specific low temperature, and (3) appropriate substrate.

These cases of heterogenous stimulus summation in the reproductive behavior of other animals, plus the evidence against the operation of any single-factor mechanism in smelts, point to the possibility that reproductive behavior of this species may also be released by cumulative action of heterogenous stimuli. One could postulate internal, hormone controlled, reproductive motivation in smelts

[2]For a critical discussion of modern ethological theory, see Lorenz (1956) and Schneirla (1956).

operating to make them increasingly sensitive to variation in daily light ration, minute increases in temperature, gustatory stimuli resulting from dilution of lake water by surface runoff, possible social releasers, and, finally, sign stimuli received in the spawning area. If such a regime does exist, the variation in time and site of smelt spawning here described could be assigned to inherited differences in level of internal motivation, to different values of the external sign stimuli received in different environments, or to both.

The postulation of heterogenous stimulus summation in the release of reproduction in smelts is not entirely without observational basis. Observations which support such a contention are:

1. Small groups of mature smelts may be seen wandering "aimlessly" about the spawning areas at night for several days or weeks before the actual beginning of the run. This can be interpreted as appetitive behavior, resulting from high internal motivation which has not yet been released by the appropriate external stimuli.
2. A large percentage of the smelt runs are initiated within a few days of ice-out. This would suggest that sudden increase in light ration, rapidly rising temperature, dilution of the lake with surface runoff, and other possible factors related to ice-out are particularly strong stimuli contributing to the release of spawning. The marked deviation of some of the runs, both between lakes and between years within one lake, indicates, however, that these are not the only stimuli which can summate to release spawning under appropriate conditions.
3. Smelts spawning during the early part of the run are sluggish and easily disturbed, suggesting a stimulus summation not greatly exceeding the threshold. Smelts spawning during the peak of the run are not at all sluggish and are very persistent in the face of disturbances. The stimulus summation is presumably much higher than threshold at the peak of spawning.
4. Bright moonlight appears to have inhibited spawning at Branch Lake for four days during 1957. On the fifth day, however, spawning occurred in spite of the moonlight. It is suggested that the cumulative effect of increasing internal and external stimulation finally raised the total stimulus level to a point sufficient to overcome the inhibitory effect of moonlight.
5. Shore spawning at Branch Lake did not begin until approximately the peak of spawning at Dean Brook. Stream conditions may have a higher releasing value for spawning than do the conditions found in the shallows of the open lake.
6. Spawning in streams with substrate of sand, boulders, and aquatic vegetation did not begin at Branch Lake until approximately the peak of spawning in a brook with a gravel substrate. Gravel may have a higher releasing value for spawning than do other types of bottom material.
7. Smelts in Branch Lake and elsewhere are highly unselective with respect to spawning area. Smelts spawn in schools and it may be that social releasers are considerably more important than are any of the sign stimuli coming from the physical environment.

The author does not consider heterogenous stimulus summation in the release of spawning in smelts to have been proved on the basis of these few observations. Experimental confirmation is required. He does consider the existence of any single-factor mechanism operating to release spawning to be very questionable.

VARIATION IN HABITAT

Freshwater smelts are considered to be "coldwater" fishes, thriving best in oligotrophic waters similar to those inhabited by Salmonidae, Coregonidae, and Thymallidae. Van Oosten (*op. cit.*) credits their scarcity in western Lake Erie and in Lake St. Clair[3] to the "shallow, relatively warm water" of those areas[3]. Green (1930) observed that smelts ". . . appear to avoid water of higher temperature than 15 degrees C." (59° F.), except for periodic ventures into warmer surface layers on calm summer evenings.

While a preference for coldwater environments may exist generally, the continuing biological survey of Maine lakes has provided

[3]Van Oosten's revised report was written in 1948. Smelts are now very abundant in western Lake Erie (Personal communication from Mr. R. G. Ferguson, Ontario Dept. Lands and Forests, Maple, Ontario).

abundant evidence that freshwater smelts are not at all confined to this type of habitat. Of 327 typical warmwater lakes surveyed in Maine through 1957, 51 have populations of smelts. The shallowest lake in this group has a maximum depth of 14 feet, and the smallest lake has an area of 12 acres. Eighteen of the lakes do not display thermal stratification. All of them are being managed for fishing for warmwater species.

The specific characteristics of one of the warmwater lakes in which smelts are present may be of interest. Sabattus Pond in Androscoggin County has an area of 1,787 acres and a maximum depth of 18 feet. The lake does not develop thermal stratification, and summer temperatures may exceed 70°F. Oxygen tension remains high at all levels in the summer, and the water is slightly alkaline. Color is light brown. The predominant bottom organisms are midge larvae and mayfly nymphs.

Fishes present are:

Osmerus mordax
Catostomus commersoni
Semotilus corporalis
Ictalurus nebulosus
Esox niger
Anguilla rostrata
Roccus americanus
Perca flavescens
Micropterus dolomieui
Lepomis auritus

The principal species sought by anglers are *Micropterus dolomieui, Roccus americanus,* and *Esox niger.* Smelt runs in the tributaries are well known and provide an annual attraction for local sportsmen.

So far as is known, freshwater smelts are found only in lakes except for their short excursions into streams during the spawning season. There is at least one exception to this rule, however. On June 24, 1958, several schools of 50 to 100 smelts each were found in the outlet stream of Duck Lake, Hancock County. This stream has an average summer flow of about 5 or 6 cubic feet per second, the width is 15 to 30 feet, the gradient is gentle, the bed is of gravel and sand, and the water is very clear. The water temperature on June 24 was 65°F.

Smelts were present as far downstream as one-quarter mile below the lake. They were in compact schools and were swimming slowly to maintain their position in the current. Some of the schools were in the open water away from shelter and were making no attempt to avoid the bright sunlight which illuminated the stream. The fish appeared healthy, they were not in spawning condition, and the stomachs of some of them contained food.

The early summer occurrence of smelts in this stream is known to local sportsmen, and smelts are commonly captured here for bait. The smelts are reported to disappear from the stream during July. They were not present when the author made a second visit to the stream in September.

Smelts often wander into the shallows of lakes in the fall after the break-up of thermal stratification. At this time, many of them find their way into lake outlets and may be swept downstream. In some cases the numbers of smelts found in outlets in the fall are quite large and give rise to the belief that a spawning run is in progress. This phenomenon is particularly well known in the outlet of Quimby Pond, Franklin County.

VARIATION IN SIZE

The maximum length attained by freshwater smelts in different lakes is highly variable. Kendall (1927) recognized this variation and discussed it in detail, accompanying his discussion with a table which presents data on sizes of smelts from 21 Maine lakes. Average lengths in different lakes ranged from 2.3 to approximately 12 inches. The largest freshwater smelt seen by Kendall was 15.75 inches, total length. Observations by the author provide confirmation of the wide variation in size described by Kendall. The usual size in most Maine waters is 4 to 8 inches, total length.

In addition to his discussion of maximum lengths attained in different waters, Kendall (1913, 1927) directed attention to the possibility that there may be two races of freshwater smelts, "large smelts" and "small smelts". Some lakes are reported to have only the large race, some have only the small race, and some have both. Kendall tentatively accepted this hypothesis and presented several items of circumstantial evidence in its favor.

Greene (1930), studying the smelt popu-

lation of Lake Champlain, accepted the existence of large and small races and presented the following as evidence:

1. The large and small groups display different growth rates. This difference was determined by reading the scales of 401 specimens taken by angling through the ice. Considerable difficulty was experienced in reading the scales of the small race;
2. The small smelts mature during their second winter while only about one-third of the large smelts mature at this age;
3. The large race feeds upon ". . . size for size . . . many more fishes than the smaller race, and conversely, far less plankton". This statement is based on examination of 140 stomachs. The difference between frequency of occurrence of fish in the stomachs of the two groups was 29 percent.

Information presented by Greene which casts doubt on the existence of two distinct races includes:

1. No anatomical basis for separating the two groups was found;
2. Smelts which display intermediate growth rates and thus can be assigned to neither race are occasionally found.

Greene realized the need for experimental confirmation of the racial integrity of these two groups and hoped to be able to accomplish it in the near future.

Zilliox and Youngs (1958), continuing the studies of smelts in Lake Champlain in 1948 and 1950, accepted the existence of the separate races without further comment.

In Maine, the existence of large and small races of smelts in the same lake is reported from many areas. It is also believed that there are two spawning runs, the large race spawning first and the small race spawning later. However, studies at two of the lakes for which this situation is reported, Mooselookmeguntic Lake, Franklin County, and Branch Lake, Hancock County, have shown only one run in each case. The run at Mooselookmeguntic Lake in 1955 began with smelts averaging 7.0 inches, total length, and continued with more-or-less regular decreases in length of the fish to an average of 4.8 inches on the last night of the run. The 1957 run at Branch Lake began with fish averaging 6.0 inches, and continued with decreases in length to an average of 3.9 inches. It is easy to see how an observer who saw the run on only a few occasions could conclude that there were two distinct groups of different-sized individuals.

The age analysis of samples of the smelts from Mooselookmeguntic Lake is presented in Table 1. These data do not provide any evidence of different growth rates in large vs. small fish. The "chopped off" distribution of the Age-II individuals does suggest that smaller, immature members of this group exist but did not come into the samples because they did not participate in spawning. The average length given for the Age-II group is thus too high.

TABLE 1.—*Age analysis of 163 smelts taken from the spawning run at Mooselookmeguntic Lake in 1955. Virtual age is equivalent to the number of annuli on the scale plus one. The Age-II individual has completed two years of life, but the second annulus will not be formed until May or June*

Total length in inches	Number of fish	Virtual age			
		II	III	IV	V
4.0- 4.9	39	38	1		
5.0- 5.9	38	24	14		
6.0- 6.9	22	5	17		
7.0- 7.9	28		24	4	
8.0- 8.9	16		10	5	1
9.0- 9.9	13		3	9	2
10.0-10.9	6			3	3
11.0-11.9	1			1	
Totals	163	67	69	22	5
Average total lengths		5.0	7.0	9.0	9.8

These examples of tentative and conflicting evidence force the present author to reserve judgment on the existence of separate races of smelts within individual lakes. Further investigation is needed before this question can be settled.

VARIATION IN ANGLING

Freshwater smelts react differently to angling in different waters. In some lakes, smelts are taken by hook and line only through the ice in winter. In other lakes they are taken only in summer. There are also lakes in which smelts are readily taken at both seasons, and lakes in which they are not caught at all. The latter situation is the most common; the smelts are seldom seen except during the spawning run or in the stomachs of game fish.

The reader will be justified in questioning these statements. How reliable are conclusions resulting from negative evidence? It is recognized that positive proof is not possible, but

the circumstantial evidence is good. In the case of winter success only, for example, there is no summer fishing for smelts even though there may be considerable fishing for other species. In lakes in which hook-and-line fisheries for smelts exist during only one season of the year, they are popular and it seems probable that enthusiastic smelt fishermen have made repeated attempts to locate similar fishing during the alternate season. Possibly these attempts yield occasional successes, but they are neither numerous nor consistent enough to stimulate a recognizable fishery.

No explanation for these differences can be offered. They may be the result of differences in population size, feeding habits, spatial distribution, or other factors. They appear not to be associated with the maximum size attained in the various waters.

DISCUSSION

As has been shown, the freshwater smelt in Maine is usually an inhabitant of coldwater lakes, it usually attains a size of 4 to 8 inches, and it is more usually taken by dipnetting on the spawning run than by hook and line. Spawning of the smelt usually occurs in tributaries or on beaches, usually at night, and usually within a few days of ice-out. However, exceptions to all these statements are common, and, in some cases, the exceptions are extreme.

Consideration of the many exceptions shown by smelt populations in Maine compels inquiry into their cause. Smelts inhabit many lakes in many distinct drainages and sub-drainages, and, despite some stocking and transplanting, it is probable that some of these populations have been isolated or partly isolated for many years. Geographic isolation is one of the more important mechanisms in speciation, and it seems entirely safe to assume that some genetic differentiation has occurred. However, we are unable to state how great this differentiation has been or how significantly it is related to the variations we observe.

The more notable differences in behavior displayed by some of the smelt populations in Maine suggest that genetic deviation might be of significance. Fabricius (1950) has pointed out, however, that animals responsive to a number of external stimuli which can summate in a variety of combinations to release the same motor response are, by virtue of this fact, extremely plastic in timing, location, duration, intensity, and general behavior with respect to that motor response in different environments. Innate differences in populations are not required to explain rather marked differences in behavior. On the other hand, variations in behavior might reflect differences in genotype if they are the result of different levels or different rhythms of internal motivation.

In addition to variation in behavior, smelts display variation in habitat, maximum size, and, probably, growth rate. The habitat differences may reflect genotype, or they may reflect nothing more than a broad tolerance to different conditions of the physical environment. The variations in maximum size and growth rate may be racial, or they may merely reflect differences in the biological environment.

The genetic constitution of the freshwater smelt populations of Maine is of significance to management. If speciation has proceeded far enough to form distinct racial groups with characteristic tolerances, growth rates, maximum lengths, and habits; the various races can then be manipulated to contribute to the attainment of a variety of fish management objectives. For this reason, further work on speciation of freshwater smelts in Maine is being pursued.

ACKNOWLEDGMENTS

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Feeding Habits of the Dolly Varden, Salvelinus malma (Walbaum), at Chignik, Alaska[1]

John F. Roos

ABSTRACT

Stomach contents of 5,050 Dolly Varden were examined during the summers of 1955 and 1956 to determine the extent of predation by this species upon young sockeye (red) salmon (*Oncorhynchus nerka*). Of 5,050 stomachs examined, 2,667 (52.8 percent) were empty. Of those containing food, 73.2 percent contained insects, and 9.0 percent sockeye salmon. In all, the 214 Dolly Varden which had been feeding on young sockeye had consumed 649 salmon for an average of 0.1 sockeye for all Dolly Varden examined.

Predation was greatest in rapid water immediately below the outlet of Chignik Lake and here 31.1 percent of the Dolly Varden stomachs contained sockeyes. Greatest predation occurs where swift current and natural obstacles restricted movement of young salmon. Dolly Varden of intermediate size (between 15 and 35 centimeters) were the most destructive to young sockeye salmon. There was a direct relationship between size of trout and proportion with food; small fish more often had food in their stomachs. It appears that Dolly Varden feed more actively during their summer stay in salt water than during their winter residence in the lakes. It seems unlikely that the Dolly Varden is a serious predator upon the salmon in the Chignik Lake drainage.

INTRODUCTION

The relationship between young salmon in their fresh-water environment and their competitors and predators has long been recognized as an important problem. Probably the most often mentioned predator of young sockeye salmon is the Dolly Varden (*Salvelinus malma*). There were no extensive studies of the feeding habits of Dolly Varden prior to the early 1930's but there has long been a general opinion that this fish is an important predator of young sockeyes. Starting in 1920, an extensive program was initiated for destruction of the trout in the Wood River lakes and other lakes in Bristol Bay, Alaska. Winn (Bower, 1922, pages 31-37) felt that the Dolly Varden, "constitute one of the most serious menaces facing the salmon industry." Although many thousands of the trout were destroyed from 1920 to 1939, the effect on salmon runs was not apparent. However, it was not clearly established that there were two species of *Salvelinus* in Alaska waters until DeLacy and Morton (1943) at Karluk Lake, Alaska, showed Dolly Varden (*S. malma*) and Arctic char (*S. alpinus*) to be present in the same river system. Recent studies by Thompson[2] proved that in the Wood River lakes the Arctic char is the most abundant *Salvelinus* present and that Dolly Varden are seldom found. It is most probable that the Dolly Varden referred to by Winn (1922) as "a serious menace" were actually Arctic char. Most of the early reports on trout-salmon relationships, whether on *S. malma* or *S. alpinus,* were based on few fish and are of little practical value in evaluating the effect of the species upon salmon.

Recently trout in two sockeye salmon lakes have been studied at Karluk Lake, Alaska, and at Cultus Lake, British Columbia. DeLacy (1941) found at Karluk Lake that "of 5,526 char stomachs examined, only twelve contained red-salmon fry or fingerlings." Of the 5,526 stomachs, 3,371 were from *Salvelinus malma,* and 2,155 were from the Arctic char (*Salvelinus alpinus*). DeLacy and Morton (1943) state, "that as judged by studies made at Karluk, the seriousness of the Dolly Varden as a salmon predator has often been overstated." On the other hand, Ricker (1941), commenting on Dolly Varden predation upon sockeye salmon, states, "the number found in individual stomachs ranges up to 93, with 10 or 12

[1] Contribution No. 50, College of Fisheries, University of Washington, Seattle, Washington. This work is part of Chignik red salmon research financed by the Alaska salmon industry.

[2] Thompson, Richard B., 1954. A study of the fresh-water predators of young red salmon in the Wood River lakes, Alaska, with emphasis on the Arctic char, *Salvelinus alpinus.* Unpublished. MS., typewritten. U.S. Fish and Wildlife Service, Seattle, Washington.

per stomach examined a common average." He examined 301 Dolly Varden stomachs during 1932-1933 and 1936-1937 and found 182 stomachs with food. Of these, 122 or 67.0 percent contained sockeye fingerlings. Ricker concluded that cutthroat trout (*Salmo clarki*) were "probably the most important predator in the lake."

Foerster and Ricker (1941) list the removal from Cultus Lake during 1932-1938 of 18,327 predator fish; of the total, 935 were Dolly Varden. It was found that concurrently with the destruction of predators, the survival rate of the young sockeye salmon showed a marked increase as measured by the number of migrant smolts counted each spring.

Biologists in the U.S.S.R. in their studies of the predation of *Salvelinus malma* (referred to as char) in recent years considered this species as both harmful and beneficial to young sockeye salmon. Krogius and Krokhin (1948) found at Lake Dalnee (Kamchatka) that "char" were feeding far more on sticklebacks than on young sockeye. The removal of sticklebacks was considered beneficial to sockeye because of their competition for food with young sockeye. On the other hand, Semko (1956), in studies in the Bolshaya River (west coast of Kamchatka), considered the char to be the main predator of sockeye fry.

Differences in the feeding habits of the Dolly Varden in all the areas mentioned clearly illustrates need for thorough investigation of the Dolly Varden in each drainage before valid evaluation can be made of their effect upon young salmon.

The only available reports of Dolly Varden studies carried out at Chignik, Alaska, are for those conducted by personnel of the U. S. Fish and Wildlife Service in 1927 and 1953. Bower (1929, page 102) reported that stomachs of Dolly Varden captured above the Chignik weir in May of 1927 were "entirely empty." The stomach contents of 100 Dolly Varden captured by sports-fishing gear in the Chignik River between May 23 and June 6, 1953, are listed by Cowan.[3] These indicated that 48 percent of the feeding fish were feeding on insects and 39 percent on salmon fry and fingerlings.

[3] Cowan, F. Kenneth, 1953. Report submitted to Richard H. Shuman, U.S. Fish and Wildlife Service, Juneau, Alaska, June 6, 1953. Unpublished, MS., typewritten.

During the summer of 1955, the Fisheries Research Institute of the University of Washington began studies of the life history of the sockeye salmon in the Chignik system, including the investigation of the feeding habits of the Dolly Varden with reference to predation on sockeye salmon, which is reported here.

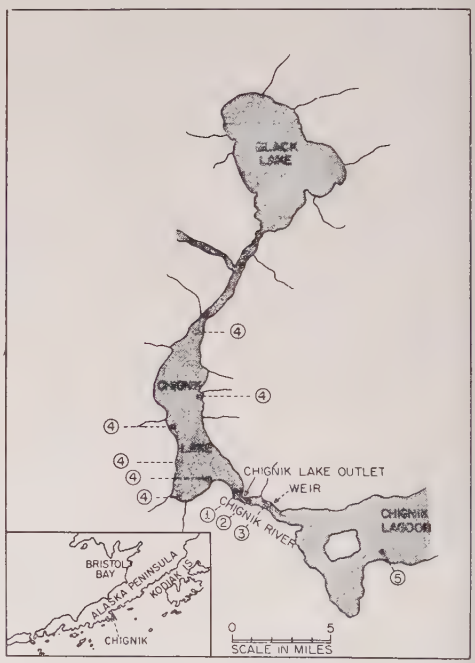

FIGURE 1.—Sketch map of the Chignik Lakes system showing the location of the sampling sites.

CHIGNIK LAKE SYSTEM AND ITS FISHES

The Chignik Lakes are on the Alaska Peninsula some 200 miles west of Kodiak Island. The two lakes, their tributaries, and a connecting river three miles in length drain into a salt-water lagoon (Figure 1). The lakes are less than 100 feet above sea level. Black Lake (the upper lake) has an area of approximately 12 square miles and is the shallower of the two lakes. Chignik Lake has an area of approximately nine square miles. The lakes are normally ice free from May through November. Tidal influence during the summer extends midway between the weir and the lake outlet. Swift currents are found in the area immediately below the outlet of Chignik Lake and average near 3.0 feet per second.

The Chignik system has long had commercially important sockeye runs. In recent years,

total runs of adult sockeyes have averaged around 800,000 fish. Young sockeyes spend from one to three years in the lakes before migrating to sea. Runs of adult coho salmon (*Oncorhynchus kisutch*) average about 10,000 fish. The remaining three species of salmon, chinook salmon (*O. tshawytscha*), chum salmon (*O. keta*), and pink salmon (*O. gorbuscha*) are seldom found in the lakes. Other fishes found in abundance in the lakes are Dolly Varden, Aleutian sculpin (*Cottus aleuticus*), and three-spine stickleback (*Gasterosteus aculeatus*). Whitefish (*Prosopium coulteriQ*, freshwater smelt (*Hypomesus olidus*), ninespine stickleback (*Pungitius pungitius*), Alaska blackfish (*Dallia pectoralis*), steelhead trout (rainbow) (*Salmo gairdnerii gairdnerii*), and starry flounder (*Platichthys stellatus rugosus*) occur in lesser numbers.

A total of 41 trout were examined in an effort to determine if both species of *Salvelinus* (*malma* and *alpinus*) were in the system. Counts of gill rakers (range from 15 to 20) and pyloric caeca (range from 21 to 33), as outlined by DeLacy and Morton (1943) were made and indicated *Salvelinus malma* as the only species sampled.

LIFE HISTORY AND HABITS OF DOLLY VARDEN

Dolly Varden migrate from the lakes to the sea during April through June and return from late July through September. They are numerous in Chignik Lagoon during the summer. Specimens from 4 to 64 centimeters in length were captured. Examination of scales of some of the larger trout (45 centimeters average length, 2 to 4 pounds) showed them to be 5 to 7 years old. Dolly Varden collected in the spring while migrating to sea had immature gonads. Many of the larger fish contained loose eggs in the body cavity, still remaining from the previous spawning season at the time of spring seaward migration. Many of the trout which return to the river in late summer are sexually mature.

TABLE 1.—*The numbers of Dolly Varden stomachs examined at Chignik during 1955 and 1956, listed by gear and sampling area*

	Location					
Gear	100 yards above outlet	100 yards below outlet	River	Lagoon	Lake	Totals
Gill net	2,207	—	—	—	—	2,207
Beach seine	633	279	206	188	97	1,403
Sports gear	—	193	1,120	—	—	1,313
Trap	—	—	127	—	—	127
Totals	2,840	472	1,453	188	97	5,050

METHODS AND MATERIALS

The 5,050 Dolly Varden were captured from May through August of 1955 and 1956 by use of four types of fishing gear: (1) beach seine, 200 feet long with a 60-by 12-foot middle panel of ½-inch nylon mesh (stretched measure) and 70-foot wings (3 feet deep at the end) of 1½-inch mesh cotton (stretched measure); (2) gill net, 120 feet by 9 feet deep with 30-foot sections of 1½, 2, 3, and 4-inch mesh (stretched measure); (3) sports-fishing tackle; and (4) wire fish trap, 6 by 16 feet on the face of the Chignik weir.

FIGURE 2.—Seine haul of Dolly Varden in the Chignik River, Alaska.

The fish were secured at five general locations shown in Figure 1. They are: (1) 100 yards above the outlet of Chignik Lake; (2) 100 yards below the outlet of Chignik Lake; (3) three stations in the river (at the weir and up to 500 yards up-river from it); (4) Chignik Lake (6 locations); and (5) Chignik Lagoon (1 location). A summary of the numbers of fish examined by gear and location is shown in Table 1.

No attempt was made to estimate the population size of Dolly Varden in the Chignik system. However, their abundance in our beach seine catches was impressive (Figure 2). Some seine catches were estimated to contain from 15 to 20 thousand fish.

ANALYSIS OF STOMACH CONTENTS

Shortly after capture, each fish was examined and the length in millimeters (tip of snout to fork of tail), sex, and stomach contents from the esophagus to the pylorus recorded. Sockeye salmon fry (age 0) and fingerlings (age I or II) were recorded separately. Individual food items other than fish were not counted nor were measurements of volume or weight taken. Results of stomach analysis are expressed as "frequency of occurrence." Each food item is given equal weight regardless of the amount consumed.

Percentage occurrence of each food item was obtained by dividing the number of fish containing a specific food by the total number of fish inspected. The individual percentages thus obtained are listed in column 3 of Table 2. Percentages of feeders (those fish with food items in the stomach) found to have been feeding on each type of food are tabulated in column 4 of Table 2.

Since differences in stomach contents of fish taken by different gear within the same general area were slight, the catch by all types of gear has been combined. Likewise results of stomach analysis for 1955 and 1956 field seasons were very similar and have been combined.

DOLLY VARDEN FEEDING HABITS

General feeding habits

Of the 5,050 stomachs examined, 2,667 (52.8 percent) were empty and 2,383 (47.2 percent) contained food. Table 2 gives the percentage occurrence of food items found in the stomachs containing food. Insects, both larval aquatic and terrestrial forms were the most frequently occurring food item; being found in 73.2 percent of the stomachs. Caddis and Diptera were by far the most common insects. These findings concur with those of DeLacy (1941) who found that "insect material was the most common type of food and occurred in the char stomachs much more frequently and in greater volume than any other type of food." Young sockeye were observed in 4.2 percent of all stomachs examined and in 9.0 percent of the feeding fish (Table 2). Sockeye was the only species of salmon identified in the stomachs.

The total of 649 sockeye salmon (473 fingerlings and 176 fry) found in the stomachs represents an average of 3.0 sockeye per Dolly Varden found feeding on salmon, or an average of 0.1 salmon for all fish examined. The maximum number of sockeye fingerlings found in one stomach was 34; the maximum number of fry, 53. The numbers of salmon consumed were far greater than the total of all other species of fish found in the stomachs. Percentagewise, other species (mainly sculpin) occurred in only 1.3 percent of all fish.

TABLE 2.—*Stomach content of 2,383 Dolly Varden examined at Chignik, Alaska, during 1955-1956*

Stomach content	Incidence of feeding	Percent occurrence - all fish examined	Percent[1] occurrence—in feeding fish
Fish:			
Sockeye fingerlings	183	3.6	7.7
Sockeye fry	31	0.6	1.3
Sculpin	47	0.9	2.0
Sandlance[2]	1	0.0	0.0
Smelt	6	0.1	0.3
Blackfish	2	0.0	0.1
Sticklebacks	14	0.3	0.6
Fish material:			
Salmon eggs	45	0.9	1.9
Salmon parts	10	0.2	0.4
Unidentified fish remains	100	2.0	4.2
Insects:			
Caddis larvae	1,024	20.3	43.0
Caddis pupae	73	1.4	3.1
Caddis adults	14	0.3	0.6
Diptera larvae	455	9.0	19.1
Diptera adults	144	2.9	6.0
Stoneflies	15	0.3	0.6
Beetles	9	0.2	0.4
Unidentified	9	0.2	0.4
Crustacea:			
Amphipods	73	1.4	3.1
Isopods	122	2.4	5.1
Ostracods	26	0.5	1.1
Miscellaneous:			
Arachnids	2	0.0	0.1
Gastropods	52	1.0	2.2
Earthworms	4	0.1	0.2
Rocks	107	2.1	4.5
Algae	15	0.3	0.6
Grass	31	0.6	1.3
Wood	8	0.2	0.3
Unidentified material	112	2.2	4.7

Number of fish with empty stomach, 2,667 52.8 percent
Number of fish feeding ..... 2,383 47.2 percent
Total examined 5,050

[1]Total of these percentages will always exceed 100 percent unless fish are feeding on only one food item.
[2]*Ammodytes tobianus personatus.*

Crustacea, primarily isopods, were present in 4.3 percent of all fish. Insects, sockeye salmon, and crustacea appeared in the stomachs of more than 90 percent of the feeders.

Feeding habits by habitat

Of the five general locations sampled, the greatest predation on sockeye salmon occurred in the rapid water below the outlet of Chignik Lake. In this area, 31.1 percent (Table 3) of the feeders had devoured young salmon but few Dolly Varden were taken.

Only a small percentage of the fish taken in the river (5.3 percent), and in the area immediately above the outlet (6.9 percent), contained sockeye salmon. None of the fish sampled in the lake proper or in the lagoon had been feeding on salmon. It should be noted that the sample from Chignik Lagoon on May 19 was taken a week before the peak of the smolt migration, and it is likely there were few young sockeye in the area.

The two sampling areas near the outlet were only a few hundred yards apart, yet large differences existed in the degree of predation upon salmon. Dolly Varden were seen in swift water immediately below the lake outlet and were in the direct path of the migrating fingerlings. On a few occasions, Dolly Varden were seen to move after a school of migrants, completely scattering the fish as they attempted to feed on them. Similar observations were made at the upstream side of the Chignik weir where larger trout were congregated. Predation was not found to be extensive in the vicinity of the Chignik weir (sockeye in 1.7 percent of the stomachs).

TABLE 3.—*Percentage occurence of food items in the stomachs of Chignik Dolly Varden captured during 1955 and1956, by area*

Stomach content	Above outlet	Below outlet	River	Lagoon	Lake
Fish:					
Sockeye fingerlings	6.1	30.7	2.4	—	—
Sockeye fry	0.8	0.4	2.9	—	—
Sculpin	1.4	4.9	2.3	—	—
Sandlance	—	—	—	1.1	—
Smelt	—	1.1	0.5	—	—
Blackfish	—	.2	0.3	—	—
Sticklebacks	0.6	1.4	0.3	—	—
Fish material:					
Salmon eggs	0.2	6.7	0.9	—	40.9
Salmon parts	0.2	1.1	0.5	—	2.3
Unidentified fish remains	2.7	7.4	6.6	—	—
Insects:					
Caddis larvae	61.6	19.8	24.1	3.3	6.8
Caddis pupae	0.3	0.4	10.2	—	—
Caddis adults	0.5	2.8	—	—	—
Diptera larvae	11.0	9.2	41.7	—	20.4
Diptera adults	8.8	3.9	1.1	—	15.9
Stoneflies	0.7	0.4	0.8	—	—
Beetles	0.4	0.4	—	—	6.8
Unidentified	0.4	1.4	—	—	—
Crustacea:					
Amphipods	—	—	—	81.1	—
Isopods	1.0	14.5	9.0	8.9	—
Ostracods	1.5	0.7	0.5	1.1	—
Miscellaneous:					
Arachnids	0.1	—	0.2	—	—
Gastropods	2.0	0.7	2.1	11.1	—
Earthworms	0.3	—			—
Rocks	1.2	12.4	6.3		31.8
Algae	0.1	2.8	0.9	—	—
Grass	0.8	0.4	3.0		—
Wood	—	1.1	0.6		2.3
Unidentified material	6.7	0.7	2.1	3.3	13.6
Number of fish with empty stomach	1,538	189	789	98	53
Number of fish feeding	1,302	283	664	90	44
Total examined	2,840	472	1,453	188	97

During the summer months, there is also an upstream migration of fry (age 0) and yearling (age I) sockeye salmon in the Chignik River from the weir to the lake outlet. These fish are 2 to 5 centimeters shorter than the older smolts (age II). On many occasions Dolly Varden attacked these fish, but usually the young salmon were observed to scatter and escape. Once the small fish reached the shallow water flowing over the sill at the outlet, they were, in many instances, unable to swim forward against the current and were consequently swept downstream into deeper water. These fish were easy prey for Dolly Varden. Of the 97 Dolly Varden captured in Chignik Lake where currents are slight, none fed upon salmon, even though young sockeye were taken in many hauls.

Sculpins, which are abundant, have been noticed with sockeye fry in their mouths in the area immediately below the outlet of Chignik Lake. One of the beneficial effects of the Dolly Varden is that they in turn prey upon the sculpins in this same area. Dolly Varden were also found to feed upon sticklebacks which abound in the lakes, and which have been seen throughout the summer feeding and migrating with young sockeye. The sticklebacks are likely competitors of salmon for food.

Insects occurred most often in the stomachs of Dolly Varden taken immediately above the outlet and in the river and lake, and were found in more than 75 percent of the stomachs. Below the outlet, 38.3 percent of the stomachs contained insects and young salmon made up most of the bulk of food consumed. In the lake, 49.9 percent of the Dolly Varden stomachs contained insects.

In Chignik Lake, 40.9 percent of the feeders contained salmon eggs and the food-containing stomachs of the Dolly Varden examined in Chignik Lagoon were filled with amphipods and isopods.

TABLE 4.—*The percentage composition of Chignik Dolly Varden by 10-centimeter size groups found feeding, and the percentage feeding on sockeye salmon*

Length of Dolly Varden in centimeters	0-10	10-20	20-30	30-40	40-50	50-60	60-70
Percentage of total examined feeding	93.7	63.5	45.0	42.2	29.7	27.0	0.0
Percentage of feeders feeding on sockeye	0.0	6.4	6.8	2.6	1.6	0.0	0.0
Total fish examined	190	981	1,397	1,755	626	100	1

Size and feeding habits

About a half of the Dolly Varden taken from the principal sampling areas were fish of intermediate size, between 15 and 35 centimeters (Figure 3). Stomachs of fish smaller than 15 centimeters did not contain salmon and salmon were found in very few of the fish larger than 40 centimeters. Because stomachs of Dolly Varden under 15 centimeters did not contain sockeye salmon, it appears that at Chignik these Dolly Varden may be possible competitors for food with young sockeye but are not predators. However, Dolly Varden of all sizes were found to be predators upon the age 0 (fry) salmon in spawning areas at Karluk; both Barnaby and DeLacy (Higgins, 1940, pages 31-33) and Walker and Bevan[4] observed predation on the fry.

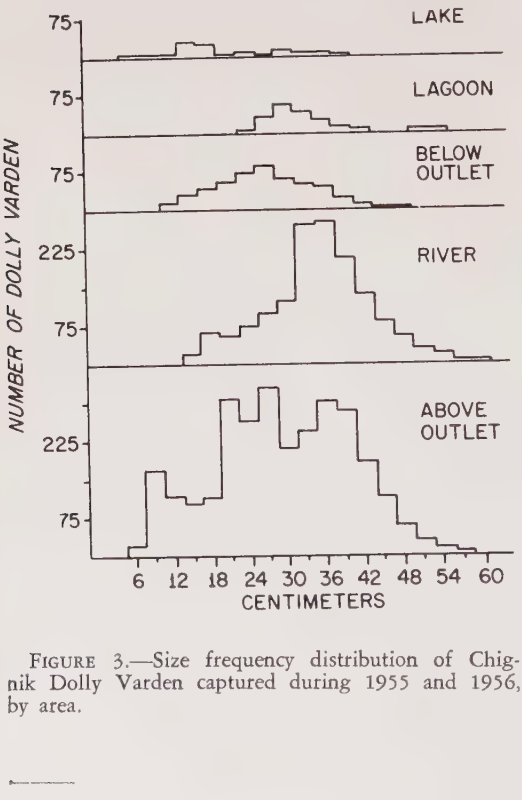

FIGURE 3.—Size frequency distribution of Chignik Dolly Varden captured during 1955 and 1956, by area.

Proportion of feeding trout was highest among the smaller sizes (Table 4). Of all fish less than 10 centimeters, 93.7 percent were feeding, but none had salmon. Only 27.0 percent of fish between 50 and 60 centimeters contained food. Insects were the most common food item throughout the size range and fish of all sizes fed on crustacea.

Feeding habits during season

Insects were the most common food item eaten by the Dolly Varden during the entire summer (Figure 4). More than 60.0 percent (Table 5) of the feeders during each month had eaten insects. Caddis larvae were most prevalent in the stomachs during the early part of the season and Diptera were abundant in July and August. In August, it was also noticed that many of the fish contained miscellaneous food such as fish scales, eggs, rocks, etc. Percentage of stomachs containing crustacea was very similar throughout the summer. Predation on salmon was heaviest in June when 23.9 percent of the feeders had salmon in their stomachs.

At Karluk, many observers have found that seaward migrating Dolly Varden do not feed on the young sockeye smolts. DeLacy (1941) found that of the 598 stomachs examined at Karluk weir in 1939 and 1940, 487 or 81.4 percent were empty. In similar studies at Kitoi Bay, Alaska, Smoker (1956) found that stomachs of Dolly Varden migrating seaward in the spring were completely empty even though these fish were migrating among large numbers of sockeyes. In contrast, Rickey (1933) found that the small Dolly Varden

[4]Walker, C. E. and D. E. Bevan, 1958. Red salmon fry in the Karluk River. Fisheries Research Institute, University of Washington, Seattle, Washington. Unpublished, MS., typewritten.

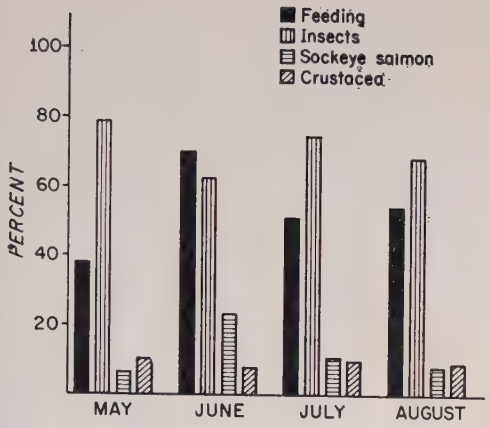

FIGURE 4.—The percentage of Chignik Dolly Varden by month found feeding and the percentage of feeders feeding on insects, sockeye salmon, and Crustacea, 1955 and 1956.

fed upon the yearling migrants during the spring as they migrated downriver from Cultus Lake. In discussing the year-round feeding habits of trout on sockeye at Cultus Lake, Foerster (1938) states, "the period of greatest loss would appear to be the summer months."

At Chignik the lowest percentage of feeding fish occurred in May as only 37.4 percent of the stomachs examined contained food. These Dolly Varden were migrating to sea. The peak of migration occurs prior to the main sockeye smolt migration; however, large numbers of both species do leave the lake at the same time. If the Dolly Varden are dependent upon salmon as a source of food, we would expect predation to occur at this time. This did not happen, as only 2.5 percent of Dolly Varden examined in May contained salmon. This would indicate that the trout do not migrate as a result of the smolt migration.

There is evidence also which suggests that for a period prior to the time of seaward migration very little feeding by the Dolly Varden takes place. Most of the fish examined at the outlet in May and June had very small stomachs with no indication that they had contained food recently. In most instances, the stomach wall was constricted.

The stomachs of the smaller trout from Chignik Lagoon on May 19 (25 centimeter average) were much larger than those of the large fish (40 centimeter average) taken at the lake outlet earlier in the spring. Most of

TABLE 5.—*Percentage occurrence of food items in the stomachs of Chignik Dolly Varden by month during the years 1955-1956*

Stomach content	May	June	July	August
Fish:				
Sockeye fingerlings	6.4	15.9	10.1	2.4
Sockeye fry	0.3	8.0	0.3	6.4
Sculpin	1.4	3.4	2.2	—
Sandlance	0.1	—	—	—
Smelt	—	1.2	0.3	—
Blackfish	—	0.3	—	0.2
Sticklebacks	0.6	1.5	0.3	0.3
Fish material:				
Salmon eggs	0.1	1.2	0.5	1.0
Salmon parts	—	0.6	0.3	1.9
Unidentified fish remains	1.4	7.9	8.1	2.3
Insects:				
Caddis larvae	75.7	58.4	16.7	12.0
Caddis pupae	—	—	9.8	2.4
Caddis adults	.	0.3	2.0	0.2
Diptera larvae	0.1	1.2	29.0	47.7
Diptera adults	2.3	2.8	15.1	4.2
Stoneflies	—	—	1.0	1.6
Beetles	0.3	0.3	0.3	0.5
Unidentified	0.3	—	0.8	0.2
Crustacea:				
Amphipods	8.3	—	—	—
Isopods	1.8	7.6	7.9	5.7
Ostracods	0.3	0.3	1.3	2.4
Miscellaneous:				
Arachnids	—	0.3	0.2	—
Gastropods	1.6	2.4	3.3	1.7
Earthworms	—	—	0.7	—
Rocks	1.1	2.8	4.8	10.2
Algae	—	—	—	2.6
Grass	0.9	2.1	1.0	1.7
Wood	—	—	0.3	1.0
Unidentified material	1.9	1.5	7.3	8.0
Number of fish with empty stomach	1,463	147	570	487
Number of fish feeding	875	327	604	577
Total examined	2,338	474	1,174	1,064

the feeders contained large quantities of food. In very few instances in the lake and river, were fish found in such condition. The Dolly Varden returning from the sea to the river in late summer were fat fish with very soft flesh as contrasted to the lean, firm fish which migrate to sea in the spring. It appears that the greatest amount of feeding takes place in the sea during the summer.

From the viewpoint of controlling predation on salmon by Dolly Varden it appears more economical and feasible to destroy trout in rapid water areas rather than to attempt a large scale program of elimination over an entire system. Since Dolly Varden feed upon both sculpins and sticklebacks, the Dolly Varden may exert some beneficial effect upon the populations of young salmon. It is concluded from the evidence obtained that they are not serious predators upon the young salmon in the Chignik system.

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Destruction and Re-establishment of Stream Fish and Invertebrates Affected by Drought

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ABSTRACT

In 1953 and 1954 a severe drought virtually destroyed the fish and invertebrate populations in Smiths Branch, a small warm-water stream in Vermilion County, Illinois, and presented an opportunity to study the adaptations, survival, and repopulation of aquatic organisms exposed to the critical conditions associated with low water levels.

The fish population in Smiths Branch was first studied in 1951. In the fall of 1953, the flow was discontinuous, most of the pools dried up, and the few remaining pools were treated with rotenone to eliminate the surviving fish. After that time, the fish population was studied through the use of an electric seine, minnow seine, rotenone, and night observation. The invertebrate population was studied in a series of bottom samples.

Discontinuous flow reduced the aquatic habitat and exposed the fish and invertebrates to desiccation, stagnation, and predation. Stagnation was most detrimental during early fall months, in association with leaf accumulations and drastic temperature fluctuations, or during the winter when ice covered the pools. Most of the fishes withstood the extreme drought conditions in at least a few parts of the stream.

Re-establishment of the populations began as soon as the stream resumed its flow. The upstream ingression of fish was limited to the first few pools above the stream mouth until the full flow was resumed, and then, during the following 2 weeks, 21 of the 29 regularly occurring species moved into most of the stream course.

Twenty-five of the regular species of fish had entered Smiths Branch by the end of the first summer after the population was destroyed in 1953. Only three species were significantly absent: The longear sunfish was not taken until the fall of 1955, and the blackstripe topminnow and hornyhead chub had not repopulated the stream when the final collections were made in September, 1957.

Most of the adult fish that entered Smiths Branch after the resumption of flow in 1954 reproduced successfully soon after entering the stream, so that young-of-the-year fish dominated the new population. The adults of some species apparently left the stream after spawning.

Fish moved over very shallow riffle areas during two brief periods of slight flow which occurred during a time that the stream was generally discontinuous.

Invertebrates displayed remarkable adaptations to drought conditions and repopulated Smiths Branch soon after the flow was resumed. The insects that were at first most abundant apparently were from adults that had flown in from other streams. The invertebrate population became re-established soon enough to serve adequately as food for ingressing fish.

The versatility of the stream organisms, adaptations and movements associated with environment and life cycles, may account for the rapid recovery of aquatic populations in Smiths Branch.

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INTRODUCTION

Organisms inhabiting the small, warm-water streams of central North America are normally exposed to severe environmental fluctuations, and during periods of deficient rainfall and reduced stream flow, are subjected to extreme physical, chemical, and biological stresses. These stresses attain their maximum intensity when the stream ceases to flow and any surface water that remains is impounded in isolated pools. Water temperatures may reach extremes and fluctuate rapidly. Evaporation, stagnation, and organic decomposition alter the dissolved salts and gases upon which aquatic life depends. Constriction of the environment changes competition, predation, and survival among the crowded, displaced organisms. Special adaptations must be made to survive and, later, to recover from these conditions.

A widespread drought that severly affected east-central Illinois in 1953 and 1954 virtually destroyed the fish and invertebrate populations in Smiths Branch, a small warm-water stream in Vermilion County, Illinois. This catastrophe presented an opportunity to study the adaptations and survival of aquatic organisms exposed to the critical conditions associated with low water levels and to observe the re-establishment of the aquatic populations as the stream habitat improved following the drought.

The drought actually extended over the years 1952 to 1955 and affected most of the central and southwestern United States. In Illinois it generally covered the southern half of the state. Hudson and Roberts (1955, p. ii) of the Illinois State Water Survey state, "On the basis of stream flow data for the period 1914-1955 the drought in 1952-1954 appears to have been a severity that would occur once in 75 to more than 10 years." Vermilion County was on the northern edge of the drought area and was not affected over so long a period as were the more southern Illinois counties. Weather records (Climatological Data, 1953-1954) collected at Danville, Illinois, approximately 13 miles east of the Smiths Branch drainage, showed below normal rainfall for 10 months in 1953 and 8 months in 1954, with annual deficiencies of 26.5 percent and 20.4 percent, respectively. Annual precipitation was not below normal in 1952 nor 1955 in east-central Illinois.

In addition to the investigation of drought conditions and their effects on the biota of the stream this study considers the versatility of stream organisms and provides information on the rate of recovery which can be expected following a major catastrophe.

DESCRIPTION OF SMITHS BRANCH

Smiths Branch, also known locally as Olive Branch, is a rather small warm-water stream in east-central Illinois which drains approximately 20 square miles of the western part of Vermilion County (Township 18 North, Range 14 West) and discharges into the Salt Fork of the Vermilion River (Figure 1). The stream receives water from very few springs; it is fed primarily by water from field tiles and surface runoff and, consequently, the flow often ceases for short periods during late summer and fall.

Both the Illinoian and Wisconsin glaciers covered this area and were largely responsible for the present topography and soil types. Drummer clay loam and Brenton silt loam are

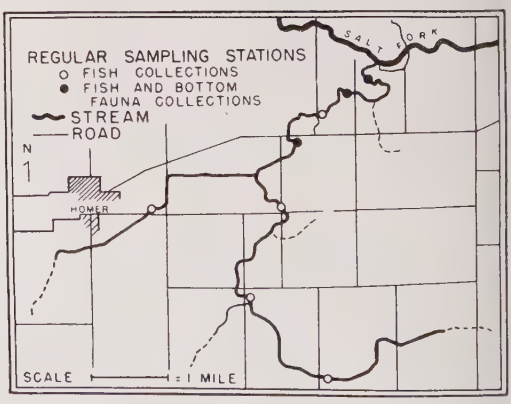

FIGURE 1.—Map of Smiths Branch and part of the Salt Fork River. Regular sampling stations are indicated.

the two principal soil types of the watershed. These loams were formed under the slough-grass and prairie-grass vegetation which covered this area after glaciation (Wascher, Smith, and Smith, 1938).

Smiths Branch may be divided into an upper section and a lower section. The upper section is made up of the east fork (6.2 miles long) with a gradient of 3.2 feet per mile, and the west fork (4.5 miles long) with a gradient of 4.9 feet per mile. This section of stream flows through intensively cultivated farm land; most of its channel has been dredged, and there are few deep pools or steep riffles (Figure 2). The stream bottom in this section is composed of silt, sand, and small gravel. The lower section (3.5 miles long) has a gradient of 13.1 feet per mile and flows through rough, wooded land (Figure 3). Here the stream has cut down through the glacial till to bedrock and has formed a moderately steep-sided valley. The pools are deeper than those in the upper section and are separated by rocky riffles. The bottom materials are primarily silt and sand, with occasional outcroppings of bedrock.

METHODS AND EQUIPMENT

Direct observations of aquatic organisms and stream conditions were made during frequent visits to Smiths Branch. Observations at night, made with the aid of gasoline lanterns fitted with reflectors, were of particular value in following the ingression of fish.

An electric fish shocker was employed in collecting fish from two areas in 1951 and again in 1952. The shocker consisted of a 30-foot electric seine powered by a gasoline-driven electric generator with a maximum capacity of 8.7 amperes of 60 cycle alternating current at 115 volts. A crew of three or four men operated the shocker and attempted to pick up all the fish large enough to stay in a ¼-inch-mesh dip net.

FIGURE 2.—Upper section of Smiths Branch.

Many other fish collections were made with a ¼-inch-mesh 4- by 20-foot common sense minnow seine. These collections were made at various times of the year, and each series covered several locations along the stream (Figure 1). They were mainly of value in determining the distribution and success of fishes which repopulated the stream.

Rotenone was used to eliminate the fish surviving the extreme drought conditions of 1953 and was later used to census fish in pools isolated when the flow again stopped in 1954 and 1955. Rotenone (Cubé) was applied to these isolated pools much in excess of the amount necessary to kill fish.

A square-foot, Surber bottom sampler was used in taking collections of invertebrates. The collections had quantitative significance only when the water was flowing sufficiently to wash organisms into the net. At other times, when the stream was pooled, the coarse bottom materials were picked up and scrubbed by hand, and then waves of water were fanned across the sample area and into the net.

Bottom samples were taken at stations 0.3, 1.3, and 2.7 miles above the mouth of the stream (Figure 1). The number of samples taken each time was influenced by stream conditions, mainly water level, although usually one sample was taken from a riffle and one from a pool at each station. The organisms were picked out of the sample material while alive and immediately preserved in 70 percent alcohol. They were later sorted into major groups, blotted to remove excess moisture, and weighed damp. Final identifications were made by specialists.

Dissolved oxygen was determined by the Rideal-Stewart modification of the Winkler method. A Whitney underwater thermometer was used to measure water temperature.

FIGURE 3.—Lower section of Smiths Branch.

CHRONOLOGY OF OBSERVATIONS AND COLLECTIONS

Our attention was directed to Smiths Branch in 1950 by anglers reporting good early-summer fishing for smallmouth bass. The fish population (Table 1) was first examined on May 14-15, 1951, when an electric shocker was used in two sections of the stream. Since that time, we have followed the annual spawning success of bass, studied daily temperature changes, and made occasional notes on stream flow, turbidity, and ice cover.

Having made these preliminary observations on the stream under average conditions (Figure 4), we were naturally interested in the effects that a severe drought would have on Smiths Branch (Figure 5) and were prepared to evaluate changes that occurred.

Figure 6 is a graphic outline of the Smiths Branch study from August, 1953, when the stream flow ceased at the beginning of the severe conditions, to October, 1955, when flow was resumed after the period of most intensive observations.

The study was continued with occasional observations for two more years (not shown in Figure 6). Stream flow was continuous from October, 1955, through September, 1956. Seine hauls were made in a series of pools on July 25, 1956, and, after the flow ceased, on October 22, 1956. Rotenone was used October 25, for a complete census of fish in several isolated pools. Smiths Branch flowed continuously during 1957. The final fish collections, seine hauls in a series of pools, were taken August 9 and September 27, 1957.

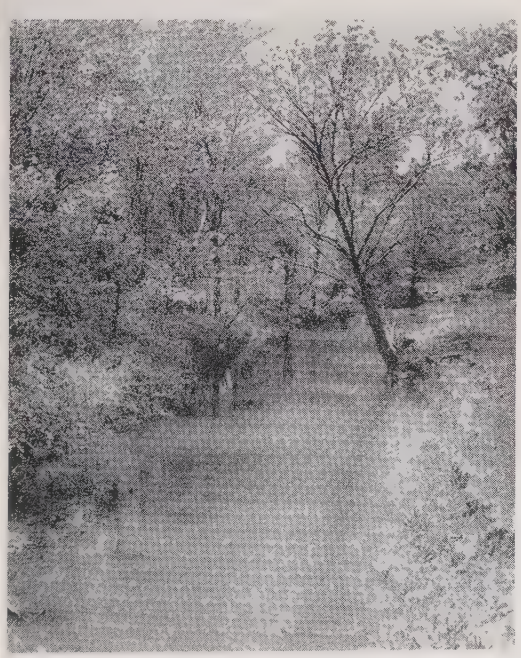

FIGURE 4.—A central portion of Smiths Branch at normal water levels.

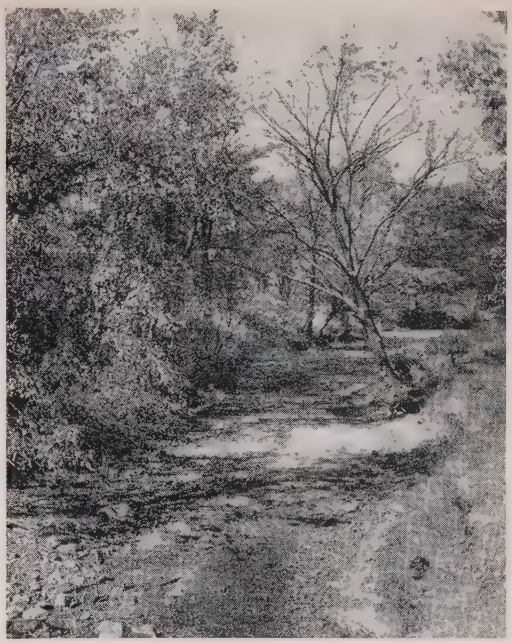

FIGURE 5.—A central portion (same as in Fig. 4) of Smiths Branch during a drought period, October 15, 1953.

The sequence of observations, collections, weather, and stream conditions shown in Figure 6 or described above must be understood in order that the results of the study can be discussed as separate topics and not necessitate following a strict chronological order. The observations on each phase of the study are brought together in the following presentation and arranged in a logical development of a topic, sometimes irrespective of the actual time sequence. For example, observations made on stagnation in September, 1956, might be discussed before those of November, 1954.

EFFECTS OF DISCONTINUOUS FLOW ON FISH

When Smiths Branch ceased to flow and the amount of aquatic habitat was drastically reduced, there was a loss of organisms as riffles became exposed and isolated pools dried up, and further loss as the few remaining pools

became too stagnant and putrid[1] to support stream-inhabiting animals.

The amount of reduction of the aquatic habitat was related to the character of the stream basin, the stream gradient, the ratio of riffle area to pool area, and, of course, to the proportion of the total volume of water that was lost. The proportional reduction of water area was lowest in the downstream area of Smiths Branch, where rather deep pools were formed in impervious materials, as clay and bedrock. Farther upstream the gently sloping riffles were composed of fairly permeable materials which allowed the water to percolate from the shallow pools soon after the flow ceased. In the extreme upper parts of Smiths Branch, the silt materials held water, but in this flat, open area the pools were shallow and were reduced quickly as a result of rapid evaporation.

Exposure of the riffle areas halted production of aquatic organisms in what is generally the most productive part of the stream. However, organisms following the receding water furnished an abundant, though temporary, food supply for the larger animals also trapped in the isolated pools (refer to following discussion of the invertebrate). Prey organisms were abnormally exposed to predatory organisms, and all the aquatic forms were especially vulnerable to the depredation of birds and terrestrial animals, such as the many herons and raccoons that foraged along the shallow pools of Smiths Branch.

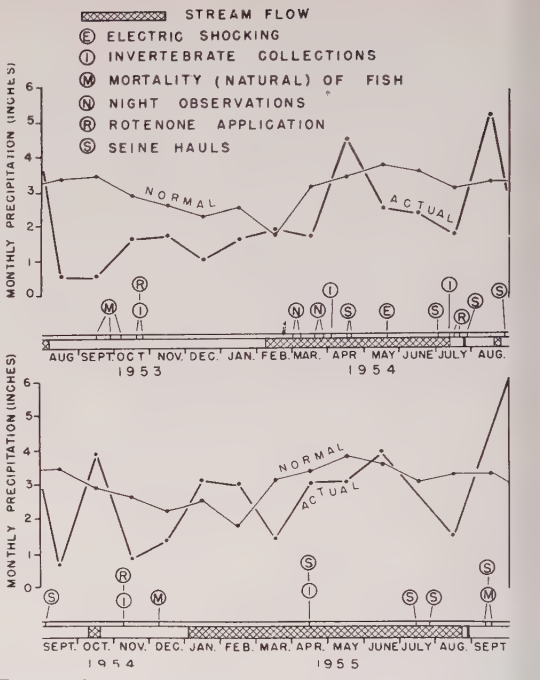

FIGURE 6.— Normal and actual precipitation for August, 1953, through September, 1955, as recorded at Danville, Illinois (Climatological Data 1953-1955). Observations (indicated by symbols) and periods of stream flow in Smiths Branch are shown on the same time scale.

Midsummer impoundment of the stream waters and stagnation was not so detrimental to fish as might be expected during this warm part of the year. Even though the supply of well-oxygenated riffle waters ceased and extreme thermal stratification was established, no fish mortality due to stagnation was seen in July or August of any year that the flow was discontinuous.

Stagnation became more destructive to aqua-

TABLE 1.—*List of regularly occurring and sporadic fishes collected in Smiths Branch, 1951-1957.* [Most of the common and scientific names are those used by Bailey (1956)]

Regularly Occurring Species

Common Name	Scientific Name
Quillback carpsucker	*Carpiodes cyprinus* (LeSueur)
Golden redhorse	*Moxostoma erythrurum* (Rafinesque)
Hog sucker	*Hypentelium nigricans* (LeSueur)
White sucker	*Catostomus commersoni* (Lacepede)
Creek chubsucker	*Erimyzon oblongus* (Mitchill)
Golden shiner	*Notemigonus crysoleucas* (Mitchill)
Creek chub	*Semotilus atromaculatus* (Mitchill)
Hornyhead chub	*Hybopsis biguttata* (Kirtland)
Suckermouth minnow	*Phenacobius mirabilis* (Girard)
Redfin shiner	*Notropis umbratilis* (Girard)
Common shiner	*Notropis cornutus* (Mitchill)
Spotfin shiner	*Notropis spilopterus* (Cope)
Sand shiner	*Notropis deliciosus* (Girard)
Silverjaw minnow	*Ericymba buccata* Cope
Bluntnose minnow	*Pimephales notatus* (Rafinesque)
Stoneroller	*Campostoma anomalum* Rafinesque
Black bullhead	*Ictalurus melas* (Rafinesque)
Yellow bullhead	*Ictalurus natalis* (LeSueur)
Blackstripe topminnow	*Fundulus notatus* (Rafinesque)
Smallmouth bass	*Micropterus dolomieui* Lacepede
Green sunfish	*Lepomis cyanellus* (Rafinesque)
Longear sunfish	*Lepomis megalotis* (Rafinesque)
Rock bass	*Ambloplites rupestris* (Rafinesque)
Blackside darter	*Percina maculata* (Girard)
Johnny darter	*Etheostoma nigrum* Rafinesque
Rainbow darter	*Etheostoma caeruleum* Storer
Orangethroat darter	*Etheostoma spectabile* (Agassiz)
Fantail darter	*Etheostoma flabellare* Rafinesque
Greenside darter	*Etheostoma blennioides* Rafinesque

Sporadic Species

Carp	*Cyprinus carpio* Linnaeus
Rosyface shiner	*Notropis rubellus* (Agassiz)
Steelcolor shiner	*Notropis whipplei* (Girard)
Brook silversides	*Labidesthes sicculus* (Cope)
Largemouth bass	*Micropterus salmoides* (Lacepede)
Bluegill	*Lepomis macrochirus* Rafinesque

[1]As used in this paper, stagnant implies foul from lack of motion and putrid refers to advanced organic decomposition.

tic animals during September and early October. Temperatures fluctuated drastically. Leaves and other dead plant materials accumulated in the stagnant pools, decomposed, and progressively increased the demand for oxygen.

An example of early fall fish mortality was observed September 12-16, 1955, after the stream flow had been discontinued for two weeks. Seine hauls were made in 15 pools scattered throughout Smiths Branch. Six of these pools were seined September 12, at which time no dead fish were seen. Four pools were seined September 15, a very hot day; fish were dying in 2 of these pools and were seen dying in other pools nearby. Five pools were examined the next day, 3 of which contained dead fish (species discussed later).

The week preceding these collections was moderately warm (air temperatures ranged between 52 and 88° F.), with a maximum air temperature of 100° F. occurring on September 9. This warm period was followed by three unusually cool days, September 11-13, when air temperatures ranged between 35° and 82° F. Then on September 15, the day many fish were seen dying, the air temperature reached 97° F. Although no fish were killed the week before when water temperatures were higher, the intervening cool days may have acclimated the fish to low temperatures to such an extent that the high temperatures of September 15 exceeded the maximum thermal tolerance of these fish. It is unlikely that the water warmed so rapidly that the shock of the actual change of temperature hurt the fish.

Decreasing amounts of daylight during the early fall months also may have reduced the thermal tolerance of fish in the stagnant pools, for Hoar (1956, p. 365) demonstrated with goldfish held at the same temperature that the short-day period fish (winter fish) are consistently more resistant to cold and less resistant to heat than are long-day period fish (summer fish).

Chemical conditions in Smiths Branch were not determined at the time the fish were seen dying, but one can speculate that the rapid warming of the unseasonably cool water, reducing the partial pressure of dissolved oxygen and producing a sudden increase in the biological oxygen demand, might have made the critical conditions produced by stagnation and decomposition intolerable to fish.

Tree leaves which accumulated in the stagnant pools in late September and October produced a deep brown stain in the water, the "black water" referred to by Slack (1955) and Schneller (1955). In 1953, "black water" conditions existed in Smiths Branch throughout the fall and winter. Pools in the wooded area were nearly filled with decomposing leaves, putrefaction was advanced, and rat-tailed maggots (*Eristalis*) were abundant. Many deeply-stained pools contained live fish when the existing pools were treated with rotenone in October, but since water conditions became progressively worse during late October and November, it seems doubtful that more than a few pools would have continued to support fish through the period of stagnation.

Fall water conditions in other years were not so severe as in 1953 but did result in fish mortality. Many dead and dying fish and dead mayfly nymphs were seen on October 22, 1956. At that time no rain had fallen for more than one month, and many pools were drying up. The declining pools in the wooded area contained great amounts of leaves, and "black water" conditions were extreme. Fish populations were low in most of the seven pools censused 3 days later and some pools contained no live fish.

On November 10-11, 1954, 2 pools in a series of 10 treated with rotenone contained no live fish. Live fish put in cages in other pools indicated that these "black waters" were not toxic at this time, but perhaps had been toxic to fish sometime during the preceding three weeks that the stream flow was discontinuous and the weather warmer.

A variety of stream fishes, not listed here because no survival differences were noted, lived in hardware cloth cages in four test pools until ice cover formed during the second week in December. On December 9, 1954, all fish in three test pools in the wooded area were dead; all fish were alive in the fourth pool which was in the upstream portion of the creek and had only an incomplete ice cover.

Oxygen determinations made a few days later (December 21) showed less than 0.1 p.p.m. dissolved oxygen in two of the pools in the wooded area where the fish had died and nearly complete oxygen saturation in the pool in the upstream area in which caged fish were still alive. All the pools at this time were covered with ice, but those with no oxygen were darkly stained and contained large leaf masses, whereas the pool high in oxygen was not stained and contained few leaves. The same pools were tested for dissolved oxygen after the stream began to flow. On January 21, 1955

the riffles were open although the pools were still covered with ice. Dissolved oxygen in the two wooded-area pools was near saturation; oxygen in the upstream pool was slightly supersaturated. About a week later, February 1, the dissolved oxygen was approximately the same, even though ice was heavier and covered more of the riffles.

The results of a laboratory study of "black water" conditions (Larimore, Childers, and McGinty, unpublished) help explain some of the field observations made during the fall months in Smiths Branch. Chemical and bacterial changes associated with "black water" were followed in a series of tanks set up with water from Smiths Branch and with tree leaves collected from along the stream bank. The following observations were made:

1. Leaves produced a high oxygen demand and a great, rapidly fluctuating bacterial population.
2. Color, pH, carbon dioxide, and dissolved oxygen levels were related to the amount of leaves in the water, and their changes were governed by the water temperature.
3. The proportion of 0.1 pound of leaves in 10 gallons of water produced oxygen deficiencies which were usually lethal to bluegills at 80°, critical at 70°, and easily tolerated at 50° F.
4. The oxygen demand was greatest within 3 to 10 days (depending on the temperature) after the leaves were added to the tanks and diminished slowly thereafter.
5. No substance toxic to the test fish (bluegills) was found in the "black water."
6. When the water surface was covered with an airtight layer, fish in "black water" with leaves died sooner than did those in clear water without leaves; oxygen declined and carbon dioxide accumulated to lethal levels even at low temperatures (50-56° F.).

These observations make the "black water" conditions in Smiths Branch more understandable. Fish mortality in October was related to relatively high temperatures and the freshness of the leaves as they first fell from the trees. In November, "black water" was tolerated because the temperatures were low. Ice on the pools caused mortality by inhibiting diffusion of oxygen into the stagnant water, by preventing the fish from gasping free air at the surface, and by allowing carbon dioxide and other substances to accumulate to toxic concentrations.

The variety of fishes surviving stagnation demonstrated the great versatility of most of the 29 species regularly occurring in Smiths Branch.[5] As already pointed out, no mortality was observed during the summer periods of stagnation even though large numbers and varieties of fish were trapped in the impounded waters.

Mortality or survival differences for various species were not obvious when fish populations from a series of pools were combined. A species absent from one pool was usually found in another pool. Fish were dead or dying in 5 of 9 pools seined September 15-16, 1955. Fewer large suckers and large sunfish were dying than small ones. Sunfish appeared to be surviving where minnows and darters were dying.

Censuses made in 1953, 1954, and 1956, after considerable mortality had occurred, contained most of the expected species. In October, 1953, when only a few pools remained in Smiths Branch and stagnation and putrefaction were well advanced, 21 of the 29 regularly occurring species were found. The quillback carpsucker, golden redhorse, hog sucker, golden shiner, suckermouth minnow, silverjaw minnow, and black bullhead were not seen, and, considering the usual tolerances of these species not collected, we believe that some of them may have been present in small numbers although they were not taken in our scattered samples. A year later (November, 1954), 19 of the 26 species that could be expected at that time (the topminnow, longear, and hornyhead chub had not repopulated Smiths Branch since their elimination in 1953) were present (Table 4). The quillback carpsucker, hog sucker, and golden shiner were absent in the fall stagnation period of both 1953 and 1954. The quillback carpsucker, hornyhead chub, suckermouth minnow, and sand shiner were absent in the October, 1956, collections (Table 4). Only the quillback carpsucker was absent each fall of 1953-1956.

The general tendency for Smiths Branch to stop flowing and become somewhat stagnant during the late-summer months has not caused any definite reduction in the number of species from that which might be expected in a stream of this type in this part of the country. In an extensive study of the fishes of Jordan Creek,

[5]The 29 species which occurred regularly and could be expected in any collection are distinguished here from the 6 species that were taken only sporadically in Smiths Branch (Table 1).

a nearby stream of about the same average size but seldom becoming discontinuous, Larimore, Pickering, and Durham (1952) found the same regularly occurring species as have been taken in Smiths Branch, with the addition of only the brindled madtom, *Noturus miurus* (Jordan), and the stonecat, *Noturus flavus* Rafinesque. These two species might be especially affected by discontinuous flow, since they are normally riffle-dwelling fishes.

Thus, it seems that most of these fishes can withstand extreme drought conditions in at least a few parts of a varied stream course. Their tolerances, linked with the likelihood that water conditions in a few pools will not reach the lethal levels, may allow survival of most species even during such severe drought periods as occurred in 1953-1956.

RESULTS OF RESUMPTION OF FLOW

There was no surface flow of water in Smiths Branch from early August, 1953, to the last of January, 1954 (Figure 6). As has been pointed out in the preceding section, the pools that did not dry up became stagnant and were treated with rotenone to kill the surviving fish. The stage was thus set to observe the re-establishment of stream flow and the ingression of fish into an area where none existed.

By the end of October, 1953, there were few pools of water anywhere in the basin of Smiths Branch. As a result of mid-November precipitation, the pools started to fill, but even after several rains during December and January the surface flow had not resumed. Pools that formed were leaf-choked and darkly stained.

On February 7, 1954, the pools spilled over and a flow was established in the central and lower part of the creek. The flow passing down the riffle areas, which were clogged with the fall and winter accumulation of leaves, was only a few inches wide. There was no flow in the far upstream reaches.

Not until March 1, approximately 3 weeks later, were fish of any kind seen in Smiths Branch. The water was still somewhat stained but was flowing steadily through narrow channels in the leaf masses which blanketed the riffles. At night, four species of minnows were observed in the lower part of the creek. The first six pools contained an abundance of minnows; ranked in decreasing abundance, they were the bluntnose minnow, common shiner, spotfin shiner, and redfin shiner. Farther upstream some pools contained no minnows or only a very few, but occasionally there was a partially blocked riffle below which were seen large numbers of common shiners and bluntnose minnows. No fish were seen more than 0.3 mile above the mouth.

One week later (March 7), no changes in the distribution of fish were observed except that the first stoneroller was seen. There was practically no open water in the long, rocky riffles, still clogged with leaves, and it was thought that the leaves blocked the upstream movements of fish. However, even after several light rains opened small channels between the pools in the lower one-third of the creek, the distribution of fish was little different on March 19 than it had been March 1 and 7. Water connections between pools were adequate for the passage of fish; apparently the ingression was halted by some other factor, possibly by unattractive water conditions still existing from the winter stagnation period or possibly because of an insufficient food supply.

The concentrations of minnows in the lower pools disappeared during the last week in March. Although only one fish (a bluntnose minnow 1.3 miles above the mouth) was seen farther upstream than was observed March 19, the minnows may have moved up and become too scattered throughout the upper pools to be readily spotted. At this time darters were seen in the pools just above the mouth of Smiths Branch. Bottom samples taken April 2, at the three established stations (Figure 1), revealed a fairly abundant invertebrate population (Table 5).

Heavy rains, April 4-7, raised the water level to a bank-full stage. Leaf accumulations were carried from the main channel; pools and riffles were flushed with fresh water for the first time in eight months.

Traps of ¼-inch wire mesh operated in the lower part of the stream and seine hauls made throughout the stream course revealed a rapid ingression of fish at this time. Twenty-one of the 29 species (Table 1) which had regularly occurred in Smiths Branch previous to its drying up had moved back into the creek within two weeks after the sudden increase in water level. The bluntnose minnow, white sucker, creek chub, and silverjaw minnow were found as far as 6.3 miles upstream from the mouth (Figure 7). The first three of these species were listed by Shelford (1913, pp. 90-91) as pioneer species in the intermittent stream community. Eight species had moved 5.7 miles or more upstream in Smiths Branch by the end of two weeks (Figure 7). These species in-

cluded 4 minnows, 2 suckers, and 2 darters.

The bluntnose minnow was the most abundant species; it was collected in fair numbers at every station upstream to a distance of 6.3 miles above the mouth (Figure 7). The redfin shiner was taken at every station up to 5.7 miles. The common shiner and spotfin shiner ranked next in abundance but occurred in significant number in only the lower pools and were not found upstream more than 5 miles. Species absent in the collections made at this time but which were taken 4 weeks later included the quillback carpsucker, golden shiner, and hornyhead chub (the latter represented by only a single specimen).

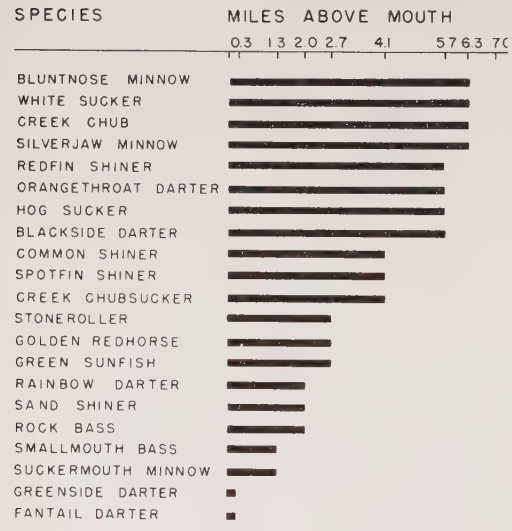

FIGURE 7.—Distribution of fish collected in Smiths Branch during the first two weeks after normal flow was resumed, April 4-19, 1954.

April, 1954, was the first month since July, 1953, to have a total rainfall that exceeded the monthly normal by a significant amount (Figure 6). Water levels permitted re-entrance of fish into Smiths Branch during a time of maximum activity for many stream species. Since March, May, June, and July rainfalls were much below normal (Figure 6), repopulation of the stream in 1954 may have been strongly influenced by the April rains, and very likely several species which did return to Smiths Branch at this time would have been scarce or absent if the April rainfall had been deficient. If ingression had been delayed until early summer, some of the spring-spawning fishes might not have reproduced in Smiths Branch. Paloumpis (1958, p. 554) found that the delay in re-establishment of a continuous flow of water in an intermittent Iowa stream delayed the spring migration and spawning of creek chubs.

On May 14 and 15, 1951, 2½ years before the entire fish population was destroyed by drought and application of rotenone, an electric seine had been used to collect fish from two sections of the stream. One section, beginning 1.3 miles above the mouth, was 433 yards long with an area of 0.75 acre. The general habitat was characterized by rocky riffles, some bedrock and relatively deep pools (considerable amount of water over 4 feet in depth). The other section began 2.0 miles above the mouth, extended 860 yards upstream, and covered an area of 1.45 acres. Riffles were composed mostly of gravel with few larger rocks; the pools were moderately shallow (little water deeper than 3 feet) with bottoms of sand and silt.

Both of these areas were worked again on on May 19 and 20, 1954, approximately 7 weeks after the stream flow was resumed. The collections from the two areas were combined in a tabulation for each of the two years. Compared to the populations found in a similar Illinois stream (Larimore, Pickering, and Durham, 1952), the numbers and weights for Smiths Branch were low in both years, but most of the expected species were represented (Table 1). In 1951 the water was somewhat turbid (estimated 40 p.p.m.), whereas in 1954 the water was very clear and permitted greater collecting efficiency. In spite of these differences in collecting efficiency, which resulted in the capture of proportionately smaller numbers of small fish (minnows and darters)in 1951, this study brings out significant differences between the original population and the population which had reinhabited the stream early in 1954.

The total fish population in 1954 had not built back up to the capacity of the area as indicated by 1951 data.

The number and weight of suckers taken in the two sections at Smiths Branch were lower in 1954 than in 1951, in spite of a much larger collection of hog suckers in the second census. Golden redhorse and white suckers, together comprising 73 percent of the number

and 79 percent of the weight of all suckers in 1951, made up only 23 percent and 34 percent of the numbers and weights respectively in 1954.

Many more minnows were taken in 1954 than in 1951. Common shiners, bluntnose minnows, and stonerollers accounted for most of the difference. The creek chub and redfin shiner appeared in about the same abundance both years. Only the hornyhead chub and silverjaw minnow occurred in significantly fewer numbers in the second collections.

Striking differences appeared in the abundance of the various sunfishes. Longears, which comprised 72 percent of the number of sunfish taken in 1951, were absent in 1954, whereas rock bass and green sunfish occurred in larger numbers in 1954. About one-third the number and one-half the weight of smallmouth bass were collected in 1954 as had been collected in 1951.

More than seven times as many darters were taken in 1954 as in 1951. As previously pointed out, water conditions were better for collecting small, bottom-dwelling fish in 1954 than in 1951. However, not all species were taken in greater numbers in the second census (Johnny darters were absent), and the proportional change in abundance was not similar for the other species. Fifteen times as many rainbow darters were collected in 1954 as were collected in 1951; they accounted for most of the great difference between the total darter collections for the two years.

Of the 29 species considered to be regular residents of Smiths Branch, only 5 were not taken by seining or shocking during April and May, 1954. The yellow bullhead, black bullhead, topminnow, longear sunfish, and Johnny darter were not collected. The bullheads may have been missed because of the inefficiency of the electric shocker in collecting them, but the absence of the other species was certain. The abundance of the different species in the Salt Fork River may have affected the actual numbers found in Smiths Branch, although the 5 species not collected were all common in the river.

The occurrence of the different fishes during the first 7 weeks after the resumption of normal flow in Smiths Branch during the spring of 1954 clearly indicated the different rates at which various species moved back into the stream and became re-established, and showed that the majority of the regular residents reentered soon after the full stream flow was resumed.

CHARACTERISTICS OF RE-ESTABLISHED FISH POPULATION

Not only did certain species move back into Smiths Branch sooner than others after the population was eliminated in October, 1953, but the various species reproduced and became re-established at different rates. These differences were seen in the collections taken in the summer of 1954 and during the following three years (Tables 3 and 4).

During the summer of 1954, 25 of the 29 regular resident species were collected. The black bullhead, yellow bullhead, and Johnny darter, missing in the spring collections, had moved into Smiths Branch and spawned during the summer although the latter 2 species were not taken in fall collections (Table 4). The longear sunfish, topminnow, hornyhead chub, and golden shiner were not found during the summer nor during the fall of 1954 (Tables 3 and 4). The absence of golden shiners was of little significance; they had been taken in the spring collections and appeared sporadically in collections of 1955 and later years. Only the other 3 species were significantly, and unexpectedly, slow to repopulate the creek.

TABLE 2.—*Numbers and weights of fish taken with an electric seine from 2.2 acres of water of Smiths Branch before (1951) and after (1954) the population was destroyed (1953)*

Species of Fish	May 14, 1951		May 14, 1954	
	Number	Lbs.	Number	Lbs.
Quillback carpsucker	7	8.12	2	0.26
Golden redhorse	89	74.85	13	10.80
Hog sucker	45	15.08	82	21.82
White sucker	63	12.66	13	0.76
Creek chubsucker	3	0.06	3	0.24
Total, catostomids	207	110.77	113	33.88
Golden shiner	....	.....	1	0.01
Creek chub	76	1.20	70	1.90
Hornyhead chub	9	0.39	1	0.01
Suckermouth minnow	....	.....	17	0.26
Redfin shiner	20	0.08	24	0.14
Common shiner	58	2.04	271	4.81
Spotfin shiner	9	0.10	48	0.35
Sand shiner	1	tr	20	0.12
Silverjaw minnow	44	0.23	30	0.21
Bluntnose minnow	128	1.37	520	4.21
Stoneroller	197	3.55	263	2.84
Total, cyprinids	542	8.96	1,265	14.86
Smallmouth bass	28	12.77	10	6.80
Green sunfish	1	0.05	12	0.91
Longear sunfish	84	3.42	....	.....
Rock bass	3	1.17	18	4.01
Total, centrarchids	116	17.41	40	11.72
Blackside darter	3		14	
Johnny darter	8		....	
Rainbow darter	18		270	
Orangethroat darter	1		11	
Fantail darter	7		19	
Greenside darter	9		28	
Total, percids	46	0.20	342	1.17

The longear, topminnow, and hornyhead chub, the last of the regular residents to repopulate the stream, were formerly abundant in Smiths Branch. They are common, widely distributed fishes in the streams of east-central Illinois, and are generally numerous near the mouth of the stream in the Salt Fork River.

In September, 1955, nearly two years after the population was destroyed, longears were again collected in the creek. Adults 4½ to 5 inches in total length were generally distributed throughout the lower 3 miles of the stream. Many sunfish less than 1 inch in length were taken at this time; although identification of these small sunfish was uncertain, collections made the following year indicated longears did establish a small, late-summer year class in 1955. They reproduced very successfully in 1956 and in October, 1956, were taken in 5 of the 7 pools censused (Table 4).

The blackstripe topminnow and hornyhead chub had not become re-established in Smiths Branch when the last collections for this study were made in late September, 1957. The only topminnow taken was a young-of-the-year collected October, 1956 (Table 4). Since no others were taken, it is doubtful if this young fish had been produced in Smiths Branch. Although the hornyhead was represented by one fish in the spring collections of 1954 (Table 2), a second individual was not taken in the creek until September, 1955, when a 1-inch

TABLE 3.—*Percentage of seine hauls in which each species of fish was taken and the average number of each species taken in each seine haul in which it occurred at 8 established stations along Smiths Branch visited April and July, 1954 and 1955*

Species of fish	April 13, 1954		July 2, 1954		April 14, 1955		July 14, 1955	
	Percentage of 69 seine hauls in which taken	Average number in seine hauls in which taken	Percentage of 30 seine hauls in which taken	Average number in seine hauls in which taken	Percentage of 50 seine hauls in which taken	Average number in seine hauls in which taken	Percentage of 18 seine hauls in which taken	Average number in seine hauls in which taken
Golden redhorse	4	1.0	.....	.....	.....	.....	33	2.2
Hog sucker	6	1.0	3	1.0	2	1.0	17	1.3
White sucker	4	2.0	67	14.0	10	1.2	61	14.6
Golden shiner	.....	.....	.....	.....	4	1.0	..	.....
Creek chub	7	1.0	77	5.6	18	1.2	89	5.4
Suckermouth minnow	.....	.....	.....	.....	4	1.0	....	.....
Redfin shiner	19	1.4	50	2.5	34	9.8	50	7.0
Common shiner	25	2.9	60	3.8	32	9.5	56	20.8
Spotfin shiner	13	3.1	50	5.7	12	3.7	28	3.4
Sand shiner	1	1.0	.....	.....	.....	.....	.....	.....
Silverjaw minnow	9	1.2	20	1.3	2	2.0	17	2.7
Bluntnose minnow	52	4.0	47	2.9	34	8.3	44	5.9
Stoneroller	12	2.0	33	1.4	10	2.0	39	9.0
Rosyface shiner	.....	.....	.....	.....	4	1.5	.....	.....
Black bullhead	.....	.....	.....	.....	4	2.5	.....	.....
Smallmouth bass	1	1.0	83	2.9	.....	.....	22	1.5
Green sunfish	1	1.0	.....	.....	6	1.3	11	1.0
Blackside darter	4	1.0	27	2.0	8	2.5	.....	.....
Johnny darter	.....	.....	37	3.2	6	1.0	33	10.5
Rainbow darter	13	1.3	13	1.8	28	3.1	33	1.0
Orangethroat darter	9	1.3	.....	.....	14	1.6	11	1.0
Fantail darter	1	1.0	.....	.....	.....	.....	.....	.....
Greenside darter	3	2.5	.....	.....	4	1.0	6	1.0

specimen was collected approximately one mile above the mouth of the creek.

The re-established population was sampled by seining at established stations (Figure 1) when the stream was flowing in April and July of 1954 and 1955. These collections (Table 3) showed the distribution and relative abundance of various species in two seasons of the 2 years following complete destruction of the population. The absence of the carpsucker, chubsucker, and rock bass in these collections can be attributed to the inadequacy of the seining method, for they were known to be present in the stream and had been taken by other collecting methods (Table 2).

In early April, 1954, few species were represented in a high percentage of the collections (Table 3). The bluntnose minnow, one of the

TABLE 4.—*Numbers of young-of-the-year and yearlings or adults of each species and the percentage of pools in which each species was found in pools of Smiths Branch treated with rotenone July and November 1954, and October 1956*

Species of fish	July 2, 1954 10 pools			November 10-11, 1954 8 pools			October 25, 1956 7 pools		
	Number of young-of-the-year	Number of Yearlings or adults	Percentage of pools in which found	Number of young-of-the-year	Number of Yearlings or adults	Percentage of pools in which found	Number of young-of-the-year	Number of Yearlings or adults	Percentage of pools in which found
Golden redhorse	8	.....	20	1	.....	12	47	2	71
Hog sucker	13	7	50	.....	.....	.....	6	6	57
White sucker	563	16	90	18	.....	50	98	26	100
Creek chubsucker	.....	2	10	10	.....	50	147	24	57
Carp	.....	.....	.....	.....	.....	.....	5	.....	29
Golden shiner	.....	.....	.....	.....	.....	.....	12	.....	57
Creek chub	1,843	66	100	251	15	100	296	23	100
Suckermouth minnow	18	.....	40	2	1	25	1	.....	14
Redfin shiner	1	15	10	4	.....	25	143	94	86
Common shiner	166	37	60	12	1	25	82	96	71
Spotfin shiner	11	2	20	1	1	25	4	6	71
Silverjaw minnow	78	1	40	10	1	38	12	.....	29
Bluntnose minnow	187	447	90	162	86	75	479	120	71
Stoneroller	739	72	90	191	22	88	418	96	86
Black bullhead	.....	.....	.....	6	.....	25	2	29	43
Yellow bullhead	9	2	20	.....	.....	.....	8	15	57
Blackstripe topminnow	.....	.....	.....	.....	.....	.....	1	.....	14
Laremouth bass	.....	.....	.....	.....	.....	.....	.....	1	14
Smallmouth bass	140	.....	90	1	.....	12	.....	2	14
Green sunfish	.....	24	10	33	.....	75	38	21	57
Longear sunfish	.....	.....	.....	.....	.....	.....	31	39	71
Rock bass	7	5	30	.....	.....	.....	2	.....	29
Bluegill	.....	.....	.....	.....	.....	.....	2	.....	29
Blackside darter	11	26	80	5	.....	12	3	2	29
Johnny darter	4	1	30	.....	.....	.....	13	30	57
Rainbow darter	33	25	70	1	.....	12	4	7	57
Orangethroat darter	11	9	60	28	.....	62	83	61	57
Fantail darter	.....	4	30	.....	1	13	2	.....	14
Greenside darter	7	.....	20	.....	.....	.....	1	.....	14

most abundant and widely occurring species in the creek during the 2 years, was taken in 52 per cent of the seine hauls made in April, 1954. At this time, the common shiner was second in occurrence but was taken in only 25 percent of the hauls.

Several species were present in 50 percent or more of the July, 1954, collections (Table 3). Except for the redfin shiner, these were species which had successfully reproduced since re-entering Smiths Branch.

More species were taken in a high percentage of the collections in April, 1955, than in April, 1954. The bluntnose minnow, common shiner, and redfin shiner were the most abundant species; they occurred in high average numbers (8.3, 9.5, and 9.8, per collection, respectively) in approximately one-third of the hauls (Table 3).

In July, 1955, most of the species were somewhat more abundant than they had been the year before. The creek chub was the most widely distributed species; the common shiner and white sucker were the most numerous where present. Nine species were represented in one-third or more of the collections. Most of the minnows, the Johnny darter, and the smallmouth bass were much more abundant in the summer than in the spring collections. The bluntnose minnow was one exception to this; it was somewhat more abundant in the spring than in the summer, apparently because it spawned late and the young were still quite small in July. Young of all species were more generally represented in the collections of July, 1955, than were adults. This was true especially of the smallmouth bass, white sucker, creek chub, common shiner, and several other minnows.

Extensive samples of the re-established population were obtained by killing the fish in a series of 10 pools isolated when the stream flow became discontinuous in July and November, 1954, and October, 1956 (Table 4). Since at least part of the population in each pool had come from adjacent areas as the flow ceased, there is no significance to the total number of fish per area of water treated. The relative numbers of the various species are reliable and meaningful, however, because the census of fish in each pool was virtually complete. These collections showed the population existing after the flow ceased, the success of reproduction in these years, and (as referred to in a preceding section) the relative abundance of young and adult fish during periods of stagnation.

In July, 1954, creek chubs were taken in all 10 pools treated; bluntnose minnows, stonerollers, white suckers, and smallmouth bass in 9 of the 10 pools. Blackside, rainbow, orangethroat darters, and common shiners were taken in more than half the pools. Creek chubsuckers, green sunfish, and redfin shiners were found in only one pool, a deep pool approximately 1.5 miles above the mouth. This restricted distribution of redfins was not expected, for it was one of the first species to re-enter Smiths Branch and to move upstream in the spring months and had occurred in 50 percent of the seine hauls made before the stream flow ceased. The spotfin shiner was also among the first to enter the stream in the spring but was found in only 2 of the 10 pools censused in the summer.

Ranked according to greatest numbers in the combined populations of the 10 pools treated in July, 1954, creek chubs were first, followed in decreasing abundance by stonerollers, bluntnose minnows, white suckers, common shiners, and smallmouth bass (Table 4). Creek chubs comprised 40 percent of the total number of fish collected and 35 percent of the total weight.

The ratio of young-of-the-year fish (1954 brood) to older fish in these pools showed the extent of reproduction of the fish repopulating Smiths Branch and suggested a post-breeding withdrawal of some of the adults from the stream.

No mature redhorse or white suckers and only one mature hog sucker were taken in July, 1954 (shown with yearlings in Table 4), although earlier in the season large suckers were numerous and produced a fair-sized brood of young. A few yearling suckers that had come up the stream in the spring still remained.

Young-of-the-year generally dominated the numbers of minnows. Two exceptions were the redfin shiner and bluntnose minnow, which were later to spawn than such species as the creek chub, common shiner, and stoneroller, whose young were abundant by midsummer (compare young-adult ratios in July and November, 1954, shown in Table 4).

The three centrarchids present spawned with different degrees of success. A very large brood of smallmouth bass was produced, but no adults remained in the pools censused. Rock bass established only a small brood and were not taken in the November census. Adult green sunfish were fairly abundant but had not yet spawned successfully; they were still

nesting in July and were successful in establishing a 1954 brood (Table 4).

Young of all the darters except the fantail were taken in the midsummer census. Even the Johnny darter, which was slow to move into Smiths Branch, established a new brood.

By the end of the summer, young of all the expected species (except the fantail darter) had been collected in Smiths Branch. The November population (Table 4) was composed largely of fish of the new 1954 brood. Adults of many species were absent.

The fall populations, already discussed in relation to tolerance of stagnation, reflected the real success of fish in becoming re-established in Smiths Branch. Relatively small populations were found after the flow stopped in November, 1954, and October, 1956 (Table 4), partly because some natural mortality had occurred in the stagnant pools previous to the censuses.

The hog sucker, yellow bullhead, rock bass, Johnny darter, and blackside darter, species that had been collected during the preceding summer, were not taken in November, 1954. At this time, white suckers and common shiners were much less abundant than they were in the summer. The large brood of smallmouth bass had virtually disappeared. Only the orangethroat among the darters had not declined, and this species was represented by only young-of-the-year (Table 4). A new brood of green sunfish was present.

Two years later, in October, 1956, the fall population was low but not to the level observed in 1954. All the expected species were present, and most of them were well distributed. The suckers and minnows were more generally distributed, both adults and young were more numerous in 1956 than in 1954. The longear sunfish was now well established. The smallmouth bass was again virtually absent in the fall population, and several darters were poorly represented (Table 4).

Young-of-the-year fish dominated the numbers in the fall censuses of both 1954 and 1956. Young were present for every species taken in the 1954 census except for the fantail darter, whereas adults of several species were absent.

From these fall censuses, it appeared that several species which returned to the stream in 1954 did not become re-established that year. After 2 years, however, most of the species which had returned to Smiths Branch had established populations.

MOVEMENTS OF FISH DURING LOW-WATER PERIODS

Smiths Branch remained discontinuous during the latter half of July and August, 1954, except for two short periods (Figure 6) when a slight flow of water passed over the riffle areas. Seven of the 10 pools which had been censused with rotenone in July (Table 4) were seined 6 weeks later to determine the extent of fish movement during the two brief periods of stream flow.

The species of minnows which were present in the July census had moved back into most of the pools in which they had been found. The suckermouth minnow was the only exception; it was found in only one of the three pools in which it had been taken in July. The redfin shiner and the spotfin shiner were taken in several pools in addition to the ones they occupied earlier.

Darters, which had been well represented in the July rotenone census (Table 4), were represented by only four individuals in these pools 6 weeks later. One orangethroat was found in one pool, two Johnny darters in one pool, and one blackside darter in one pool.

Creek chubsuckers, redhorse, and white suckers moved back into the pools during this low-water period, but hog suckers were not found in any of the pools sampled.

Smallmouth bass had moved back into only three pools and were represented by but one or two specimens in each place. More is involved here than lack of movement back into the treated pools. Evidence of a general disappearance of young-of-the-year smallmouths was obtained by seining seven pools (not in the series of pools poisoned) July 26, 1954, and again August 26. An average of 27 fingerling bass per pool was collected and returned in July; a month later bass fingerlings (four specimens) were found in only two of the seven pools. The scarcity probably was not due to mortality, since all the pools contained other live fish, but more likely to a mass withdrawal of these young fish from the creek during the two short periods of flow. Further evidence of late-summer disappearance of smallmouth fingerlings can be seen in Table 4.

Green sunfish had moved into two of the previously treated pools, whereas rock bass were not found in any of them.

Fish movement, indicated by fish found in these pools six weeks after treatment with rotenone, was extensive among only the min-

nows. However, most of the species displayed some movement during the two very brief periods of stream flow.

EFFECTS OF DISCONTINUOUS FLOW ON INVERTEBRATES

The invertebrate fauna in Smiths Branch was considered in this study primarily because of its importance as food for fish. Our first concern was whether or not the invertebrate population following the drought conditions was adequate to support the re-established fish population. Had the invertebrate population been destroyed or only reduced during the dry months? Did the invertebrates build up as rapidly as did the demand for them? Did the re-established invertebrate populations include species acceptable as fish food? Were some species absent which ordinarily are important food items for fish? More subtle questions concern the biology of the invertebrates without regard to their value as fish food. How do the invertebrates adapt to conditions of stagnant water or desiccation? How is survival or ingression related to the life cycle of the species?

Although we have not satisfactorily answered these questions, we have made observations which may contribute to their solution and which show the dynamics of an invertebrate population affected by drought.

During the fall months of 1953 when the stream bed was dry throughout most of its length (Figure 5) and many of the remaining pools were stagnant and foul smelling, the invertebrates were exposed to extreme conditions. Some organisms were successful in meeting these conditions; others were not.

Desiccation was the first drought condition to threaten the invertebrates. In the summer of 1953 and again in 1954 when the stream flow ceased and the shallow areas were no longer covered with water, many invertebrates were left on the drying stream bed; others withdrew as the waters receded and were crowded into smaller and smaller pools, many of which eventually dried up.

The invertebrates resisted desiccation in several ways. Some insects became encased in the hard silts and clays of the dry stream bed. An adult water scorpion (*Nepa apiculata* Uhe.) was found, dormant but alive, encased in silt an inch below the surface of the dry stream bed. Other invertebrates such as water striders (Gerridae), crayfish, and hellgrammites (*Corydalus cornutus* L.) remained in damp chambers under flat rocks, where they survived long after the free water had left the sand and gravel of the substratum.

Some animals avoided desiccation by seeking new areas which were moist. Flying insects or forms able to walk or crawl across long dry stretches may have moved to other bodies of water—springs, seepage spots, other streams, or ponds—which had not dried up during the drought. Another escape for the invertebrates was to dig down into the bottom materials to find moisture and reduce water losses from their bodies. Stonefly and mayfly nymphs, beetle, caddis fly, and dipterous larvae, snails and isopods remained in moist surface materials after the waters receded from over them; but as these materials became drier, the organisms retreated to more moist, deeper layers. They followed the moisture to considerable depths (one foot or more) in areas where sand and gravel were deep and where burrowing was not prevented by hard clay or bed rock.

Stagnation of the water impounded after the flow ceased presented another threat to the invertebrates. The remaining pools, already crowded with organisms which had retreated with the declining water, became smaller and smaller as the dry period continued and water conditions became progressively worse. There was an increased demand for oxygen, a greater production of carbon dioxide, and more extreme fluctuations of temperature (see section on Effects of Discontinuous Flow on Fish). Organisms which earlier had moved into these pools to avoid desiccation now had to adapt to critical conditions or leave the water.

Differences in specific tolerance of these conditions brought on changes in the composition of the pool populations. As the conditions accompanying stagnation became increasingly severe, fewer species were found alive. Coming to the surface or resting only partly submerged were ways by which a few surviving invertebrates utilized free air. Some organisms (for example, mayfly nymphs, larval and adult beetles, and isopods) moved into the organic debris and bottom materials surrounding the pools, where they avoided the most toxic situation but still had water which filtered through sand and gravel. Crayfish were seen leaving these foul-smelling pools. The rat-tailed maggots (*Eristalis* sp.) were the only insects generally found in the most putrid waters; with their special tolerance and adaptations, they thrived after the other invertebrates were gone.

The pools along Smiths Branch refilled with water during the winter months of December, 1953, and January, 1954. Although there was very little flow over the riffles and the waters remained darkly stained, early in the year the stream provided an aquatic habitat which supported many invertebrates.

On March 7, 1954, gerrids were generally all along the stream and were especially abundant in the lower reaches. Water beetles, a hydrophilid and a dytiscid (*Laccophilus* prob. *fasciatus*), were seen in the lower pools. Bottom samples taken later in the spring indicated that invertebrates had been moving back into Smiths Branch during February and March and that the population surviving the drought had been expanding.

Square foot bottom samples were taken April 2, 1954. There was a moderate flow of water over the riffles, but the water level was still very low; the riffles were shallow and not spread out over the widths of the stream bed. Tendipedids occurred in every collection and far outnumbered all other organisms taken. Other dipterans (*Tabanus* and *Eristalis*) were represented by only a few individuals. Stonefly nymphs were taken in every sample. Mayflies were the only generally common aquatic insects not represented.

The stream ran full from early April to late June, but the flow again became discontinuous just before bottom samples were taken July 13, 1954. The most obvious population changes since April were the decline (through emergence) of tendipedids, the appearance of mayfly nymphs in relatively large numbers, and an increased abundance of crayfish in many of the pools. Although the riffles had no water passing over them, they were moist at the surface and water could be reached at depths of 3 to 4 inches. They were moderately well populated with aquatic organisms (Table 5).

The stream flow was intermittent from early July to November, 1954 (Figure 6), when samples were again taken. The riffles were dry to considerable depths and did not support aquatic organisms. The pool populations indicated that many of the riffle-dwelling forms had moved into the pools during this long dry period. There were relatively few crayfish but an abundance of isopods in some of these stagnant pools.

The stream did not flow during the early part of the following winter of 1954-55, and the stagnant pools became putrid with rotting organic materials, mainly leaves. Smiths Branch was flowing bank full by the middle of April, 1955, when more bottom samples were taken. Riffles were better populated and pools more sparsely populated at this time than they had been the year before in April, 1954. Tendipedids were less abundant, especially in the pool samples, in April, 1955, than in April, 1954, whereas oligochaetes, snails, beetles, and caddis fly larvae were more abundant (Table 5).

The bottom fauna in Smiths Branch was not studied before the 1953 drought, so that a "before and after" comparison could not be made. However, collections taken in Jordan Creek, a nearby stream of about the same average size but with a continuous flow during most dry periods, may be of some value in appraising the effects of the drought and the subsequent recovery of the Smiths Branch invertebrate population. Quantitative comparisons cannot be made on so few samples, but it seems apparent that the spring population in Smiths Branch was within the range of fluctuation that may be expected in such streams and that the severe periods of drying and stagnation were only slightly more destructive or lasting than the influences that had acted on the Jordan Creek invertebrates, which had not experienced such severe conditions. In a comparison of the two streams, it appears that the intermittent flow in Smiths Branch reduced the invertebrate population in the riffles more than in the pools, as would be an expected consequence of the earlier and more prolonged drying of the riffle areas.

The abundance of various invertebrates[6] after the drought period was related to their life cycles, motility, and adaptability. Forms which appeared infrequently in the collections or which could not be sampled effectively (e.g., crayfish) with the method employed were omitted from the quantitative tabulation (Table 5).

[6]Identifications of various invertebrate groups were made by the following persons: Dr. H. H. Ross (Trichoptera, Plecoptera, larger Diptera), Dr. M. W. Sanderson (Coleoptera), Mrs. Leonora K. Cloyd (Ephemeroptera), and Dr. H. B. Mills (Collembola), all members of the Illinois Natural History Survey; Dr. Arthur A. Johnson, Hendrix College (Nematoda); Dr. James A. Macnab Portland State College (Annelida); Dr. H. H. Hobbs, Jr., University of Virginia (Decapoda); Dr. Max R. Matteson, University of Illinois (Mollusca); and Dr. La Verne L. Curry, Central Michigan College (Tendipedidae). Comments by these specialists on the ecology and life cycles of the invertebrates were of great value in interpreting the populations in Smiths Branch.

Some probable relationships of population composition and stream intermittency are briefly set forth in the following list of major taxonomic groups.

Nematoda.—All the specimens collected (27) were identified as belonging to the family Mermithidae; 23 were in the genus *Hydromermis,* 2 *Bathymermis,* 1 *Mesomermis,* and 1 *Amphidomermis.*

Aquatic mermithids are parasitic as larvae in insects. All the worms were taken in April and were in the last larval stage or were adults; several worms (*Hydromermis*) were emerging from tendipedid larvae when collected. Tendipedids were especially abundant and were transforming to adults at this time.

Nematodes are generally very resistant to desiccation and temperature extremes and might be expected to survive drought conditions. The rapid, early spring development of tendipedids provided hosts for the larval worms. Smaller, non-parasitic aquatic nematodes may have been numerous but too small to be taken in the collecting net.

Annelida.—Most of the specimens were in the family Tubificidae, with the genera *Limnodrilus, Tubifex, Monopylephorus,* and *Rhizodrilus* being represented. Enchytraeidae and Haplotaxidae (*Haplotaxis*) were collected in small numbers and, except for a specimen of *Haplotaxis* taken in November, 1954, all were collected in April, 1954, following resumption of water flow.

The greatest numbers of tubificids were taken from pools during periods of stagnation (July and November, 1954) but tubificids were also rather plentiful in the April, 1955, riffle samples. Tubificids are especially tolerant of the stagnant water conditions which develop in an intermittent stream, since they thrive in low concentrations of dissolved oxygen and can endure the absence of oxygen for rather long periods.

Plecoptera.—*Allocapnia* sp. was the most commonly occurring stonefly. Large nymphs about ready to transform and small nymphs were collected in April, 1954. None was taken in July, but small ones appeared in the November samples. In April, 1955, large and small nymphs, as well as recently emerged adults, were again taken. These stoneflies adapted to the drought conditions and maintained an annual cycle in Smiths Branch during the dry years.

TABLE 5.—*Number of organisms per square foot in samples taken during 1953-1955 from Smiths Branch and the number (in parentheses) of samples in which the organisms occurred* [This table does not include Decopods, Pelecypods, and several insect groups which occurred infrequently]

Kind of organism	October 23 1953	April 2 1954		July 13 1954		November 11 1954		April 14, 15 1955	
	Dry stream bed	Riffle	Pool	Dry riffle	Pool	Dry riffle	Pool	Riffle	Pool
	2 samples	6 samples	2 samples	3 samples	3 samples	2 samples	3 samples	6 samples	2 samples
Nematoda	.....	3.0 (3)	2.5 (1)	.....	.....	.....	.....	1.0 (3)	.....
Freshwater Oligochaeta	.....	3.2 (3)	10.0 (1)	.....	7.7 (3)	.....	40.6 (3)	33.8 (6)	21.5 (2)
Diptera-adults	.....	29.5 (6)	6.0 (2)	.....	.....	.....	.....	4.0 (3)	2.5 (2)
-pupae, larvae	4.5 (2)	144.6 (6)	163.0 (2)	2.0 (3)	23.0 (3)	.....	7.0 (3)	54.1 (6)	17.0 (2)
Coleoptera—adult	6.5 (2)	1.2 (3)	.....	3.3 (3)	.....	....	2.6 (2)	1.2 (5)	.....
—pupae, larvae	2.0 (2)	1.0 (2)	1.5 (2)	1.3 (2)	0.3 (1)	.....	.....	6.3 (5)	.....
Ephemeroptera	.....	....	.....	19.0 (3)	17.0 (3)	.....	.....	2.0 (6)	.....
Trichoptera	.....	1.0 (3)	1.5 (1)	6.6 (3)	.....	.....	.....	165.8 (6)	14.5 (1)
Plecoptera	.....	5.3 (6)	13.0 (2)	0.3 (1)	.....	.....	2.3 (1)	9.8 (4)	.....
Copepoda	.....	2.1 (3)	0.5 (1)	.....	.....	.....	1.6 (2)	0.3 (1)	.....
Isopoda	0.3 (1)	0.7 (2)	3.0 (2)	2.6 (2)	0.6 (1)	....	2.3 (1)	.....	.....
Gastropoda	.....	.....	.....	0.3 (1)	.....	.....	4.3 (1)	13.0 (4)	0.5 (1)
Average number per sample	6.6	31.9	100.5	11.8	16.2	.....	20.2	48.6	28.0
Average weight per sample, in grams	0.541	0.211	0.330	0.568	0.194	0.000	0.145	0.508	0.041

Isoperla sp., although absent in the 1954 collections, were abundant in April, 1955, the brood having come from eggs laid in 1954. Two small *Taeniopteryx* sp. were picked up in April, 1954, and one *Acroneuria* sp. was taken in July.

Ephemeroptera.—Nymphs of both burrowing and crawling mayflies were taken in moist sand and along the edges of stagnant pools in October, 1953, but since no nymphs were taken in the samples collected the following April, 1954, it is apparent that extensive or complete destruction of the mayfly population occurred during the dry fall and winter months of 1953-54.

By July, 1954, a large mayfly population was re-established; *Ephoron leukon* Williamson occurred in fair numbers in 5 of 6 samples, and *Caenis* sp. in all of the 6 samples taken. Mayflies were again absent in the collections of November, 1954, after 4 months of discontinuous stream flow. Although early-instar nymphs (*Pseudocloeon* sp. was identified) occurred in 6 of 8 samples in April, 1955, only a few specimens were collected.

Mayflies commonly have two flights each year, one in the spring and one in the summer. It appears that flights of adults from nearby streams in the spring months were the primary source of nymphs found in Smiths Branch in July. Nymphs hatching from eggs laid by the second flight apparently did not withstand the dry, stagnant conditions which prevailed in late summer and early fall of 1954.

Trichoptera.—Large larvae of *Rhyacophila lobifera* Betten and *Limnephilus submonilifer* Walker (?) which were taken in collections of April, 1954, had survived the drought conditions of the previous fall and winter. Although larvae of *R. lobifera* were not taken in July, probably because they were quite young and small, they were again fairly numerous in April, 1955. Many were in pupal cases at this time. Ross (1944, p. 35) points out that this species frequents small streams that are of a temporary nature in dry years.

Cheumatopsyche sp. was absent in April, 1954, abundant in July, and absent again the following April, 1955. The large midsummer brood had developed from eggs laid in May when the stream was flowing. They were collected in July, 1954, from riffle areas exposed after the flow stopped and were not taken in any of the pool collections. It appears that this caddis fly did not survive in Smiths Branch throughout the years (1953-54) when conditions imposed by low water were severe.

The small larvae of *Ochrotrichia xena* (Ross) occurred in abundance in April, 1955. At this time, as many as 562 per square foot were collected, and as they occurred in 7 of 8 samples, they appeared to be distributed throughout the stream. These larvae came from eggs laid the previous year (1954) and as eggs or larvae had survived the dry fall months of 1954.

Coleoptera. — *Stenelmis sexlineata* Sand., *S. crenata* Say, and *Dubiraphia quadrinota* Say, all of the family Elmidae, occurred in more collections and in greater numbers than any of the other species of beetles. Larvae and adults of both genera were present in April, 1954, after the stream flow was re-established. *Stenelmis* larvae were quite numerous in the April collections of 1955.

The presence of these beetles in considerable numbers after the severe drought conditions in the fall of 1953 and moderately severe conditions in 1954 indicates their adaptability to stagnation or desiccation of the habitat. These true aquatic beetles, which ordinarily spend their entire lives submerged in water, were collected in the moist sand and gravel of exposed riffle areas after the stream became intermittent in July, 1954. However, in November, after these areas had been dry most of the time during the fall months, no adults or larvae of these species were found in the exposed bottom materials.

Other aquatic beetles collected occasionally during or after the dry periods included *Spherchopsis tesselatus* Ziegler, *Cymbiodyta blanchardi* Horn, *Enochrus* sp., and *Berosus* sp. of the family Hydrophilidae, all taken from exposed, drying bottom materials. In the family Dytiscidae, adults of *Agabus semivittatus* Lec. were taken from moist gravel, *Hydroporus* sp. from a stagnant pool, and a *Coptotomus* larva from an isolated pool. Adult haliplids, *Peltodytes punctatus* Say or *P. lengi* Roberts, were found in stagnant pools.

Many other beetles, not aquatic species, were collected in October, 1953, in the exposed, drying bottom materials. These terrestrial beetles probably were feeding on organisms which had succumbed to the drought conditions. The list of nonaquatic species that could be found in this association might be quite extensive; occurring commonly were four species of Staphlinidae, one of Scaribiidae, and one of Carabidae.

Diptera. — Midge larvae (Tendipedidae) were the most numerous organisms in the spring collections of both years. On April 2, 1954, before the stream flow had attained a near average volume after the dry period, these larvae were abundant and large numbers of adult midges were emerging. To have completed their development this early in the spring, the tendipedids must have been numerous as larvae at a time when the pools were filled with decaying leaves and highly-stained water and were connected only by seepage through exposed riffles. They probably were an important source of food for the ingressing fish. Only small numbers of tendipedids were taken in the July and November collections (Table 5).

Cricotopus exilis Johannsen was the most common midge in the large spring collections. Others present in the spring were *Cardiocladius* sp., *Anatopynia* sp. near *fastnosa,* Hydrobaeninae (Orthocladiinae), and *Paratendipes* sp. probably *albimanus* (Meigen). *Tendipes* sp. near *tuxis, Tanytarsus* sp., and Hydrobaeninae comprised the summer collections.

Diptera larvae, other than tendipedids, that were common included the rat-tail maggot (*Eristalis* sp.) from stagnant pools, three species of the old genus *Tabanus,* and a stratiomyiid from bottom materials of the dry creek bed. All these, except the last named, were also taken in April, 1954, after the stream was again flowing.

Isopoda.—Although a few isopods (*Asellus,* probably *brevicaudus* Forbes) were taken from the stagnant pools in October, 1953, and from the flowing stream the following April, 1954, they were found most numerous soon after the stream became intermittent in July, 1954. They were abundant in some of the stagnant, leaf-choked pools in November, 1954, but were not collected in April, 1955. Their absence in these last collections is not conclusive evidence that they suffered heavy mortality during the intervening winter months but possibly that their distribution in the flowing stream was such that they were not picked up in the few samples taken.

The specimens collected in April, 1954, were in late instars and had survived the rigorous conditions which prevailed during the fall and winter of 1953. Those collected in July, 1954, were young specimens that had been produced in Smiths Branch during the spring months.

Decapoda.—Crayfish (not shown in Table 5 because they were not adequately sampled by our methods) were especially adaptable, as discussed on a preceding page, to intermittent stream flow and the associated environmental extremes.

Three species were abundant: *Orconectes propinquus propinquus* (Girard), *O. virilis* (Hagen), and *Procambarus blandingii acutus* (Girard). *Cambarus diogenes diogenes* Girard occurred only occasionally.

Because of their adaptability to conditions which were generally unfavorable for most invertebrates, the crayfish maintained large, reproducing populations in Smiths Branch. They were generally abundant and at times appeared to be present in enormous numbers, such as when the water level was low during the summer months and the crayfish were crowded into the remaining, reduced water areas. They appeared scarce only during the fall months, when some of the pools in the downstream area became stagnant and foul-smelling; crayfish seemed to avoid these waters but survived in the surrounding damp sand and gravel of the exposed stream bed. Extensive mortality occurred, however, when long sections of the stream bottom became very dry to considerable depths, as in some areas during the fall of 1953.

Gastropoda.—No snails were found in the stream the first months after the flow was reestablished in 1954. One *Physa eliptica* was taken from a drying riffle area in July and young of *Physa* and *Fossaria* were taken from one pool in November. However, 5 of 8 samples in April, 1955, contained snails (as many as 40 per square foot, plus many egg masses) of the species *Fossaria obrussa, F. parva,* and *F.* probably *exigua. Ferissia,* young *Campeloma,* and 1 *Columella edentula* (a land snail) were also taken.

Aquatic snails hibernate, aestivate, and make special adaptations when their habitat becomes dry. Some of the pulmonate snails become encased in mud during dry periods and close their aperture with a sheet of mucous produced by the foot. Although conditions existing during the drought period of 1953 appear to have greatly reduced the snail population in Smiths Branch, the snails that survived produced a large population by the end of the following year.

Miscellaneous Groups.—Several groups of invertebrates were represented by only a few individuals in our collections; they were of

less obvious importance in the stream than the more abundant forms but nevertheless their mere existence in the stream during these dry years may be of interest. Their occurrence in the 30 samples taken between October, 1953, and April, 1955, was as follows:

Turbellaria, in 2 samples, April, 1955.

Hirudinea, in 3 samples, fall 1953 and 1954. *Erpobdella punctata* (Leidy)? identified.

Copepoda, no doubt more abundant than our collections indicated (Table 5). The production of stages resistant to desiccation permits survival during extreme drought periods.

Collembola, in 2 samples, April, 1954. *Isotomurus palustris* (Müller) identified.

Hemiptera, in 4 samples, fall of 1953 and summer and fall of 1954. Nepidae and Corixidae represented.

Megaloptera, 1 sample, fall of 1953. *Corydalis cornutus* L. identified.

Neuroptera, in 2 samples, summer 1954. One specimen, a Sisyrid, identified as *Climacia areolaris* Walker.

Pelecypoda, in 2 collections, fall 1953 and summer 1954. Several unionids survived the dry periods (*Amblema costata, Strophitus rugosus,* and *Carunculina parva* picked up September, 1955) but were not taken in our regular sampling.

Many terrestrial insects were taken from the exposed bottom materials when the stream was intermittent; most of these terrestrial forms were predators or scavengers feeding on the aquatic organisms which were dying or being displaced by the receding water level.

DISCUSSION

S. A. Forbes (1883, p. 95) pointed out that in an aquatic habitat where wide and violent fluctuations and continual readjustments are the rule, the system of life must be relatively flexible and a species existing in such a system must have within itself recuperative powers to rally against the most destructive recurring attacks. In the Smiths Branch study, aquatic organisms were observed under environmental extremes; they were seen adjusting to adverse conditions and were followed in their recuperative processes.

Because the nature of the Smiths Branch drainage basin is such that low water levels or periods of discontinuous flow occur even during years of rather normal rainfall, the organisms found in Smiths Branch belonged to species capable of adjusting to, or recuperating from, unfavorable stream conditions. Although catastrophes of various extents and intensities are common in most small streams, the 1953 Smiths Branch catastrophe completely eliminated certain aquatic groups, and the fish surviving the drought were killed by the application of rotenone to the stagnant pools.

In discussing the fishes of Champaign County, Illinois, Thompson and Hunt (1930, p. 47) stated that headwater fishes are "apparently capable of meeting all situations and reaching large numbers under conditions more rigorous than others can endure. They are generalized morphologically and have a wide range of physiological adaptability." The headwater species listed by Thompson and Hunt were common fishes in Smiths Branch. These fishes tolerated crowding in stagnant pools when the Smiths Branch flow ceased and then dispersed quickly when the stream flow was re-established. Starrett (1950a, p. 122) concluded that certain species abundant in the Des Moines River were not more widely distributed in tributary streams because of their inability to withstand oxygen reduction and the crowded conditions in small intermittent pools in late summer.

Different tolerances or rates of survival could not be determined with certainty among the fishes of Smiths Branch, for most of the regular stream species survived such extremes that they were usually represented up until water conditions became intolerable to all the fishes present. The fishes Wickliff (1945, p. 25) found surviving in almost dry pools of Blacklick Creek, Ohio, were all species that were tolerant of the drought conditions affecting Smiths Branch. Wickliff (p. 24) observed that "small fish may be crowded and survive for weeks or months if excessive decomposition does not develop, or if the pool does not dry up, or if predators do not eat the fish." James (1934) summarized the effects of the 1934 drought in the western and midwestern United States. He stated (p. 61): "Deoxygenation from several different causes, intensification of pollution, destruction of food, attacks from predators and human fish hogs are cited as the means whereby water-shortage ravages the aquatic population."

Several of these conditions have been pointed out as related to survival of fish in Smiths Branch during periods of discontinuous flow. Predators apparently ate great numbers of fish in shallow pools in Smith Branch, but the mortality due to "excessive decomposition" was unimportant during the summer, occurring

mostly in the fall months in association with accumulations of tree leaves in the stagnant pools. Neel (1951, p. 386) showed that the chemical relations in a stream are affected mainly by decomposition and photosynthesis and that the quantitative effects of both processes are largely controlled by the volume of water moving down the stream. He stated, "Decomposition, which often neutralizes the influence of photosynthesis, has its heyday in the fall."

Although the leaf accumulations that stained the water a dark brown did not yield toxins lethal to Smiths Branch fish, the leaves produced oxygen demands which were lethal during extreme fluctuations of water temperature, or when ice covered the leaf-stained, stagnant pools. Schneller (1955, p. 174) concluded that "black water" rarely causes fish mortality in Salt Creek, Indiana, which becomes stained in the autumn but continues to flow. On the other hand, Slack (1955, p. 27), in studying an Indiana stream after the flow had ceased, observed fish, tadpoles, and various invertebrates surfacing to breathe, and some dead fish. He found dead fish after an ice cover on the pool had prevented surface breathing.

Some adaptations of insects to environments that are alternately dry and flooded were discussed by Hinton (1953). Gill structures, permeability of the cuticle, and tolerance of dehydration were morphological adaptations he mentioned which could be related to survival of Smiths Branch invertebrates. Also of application to the present study were some of the factors listed by Hoffman and Drooz (1953) that prevented eradication of aquatic insects following widespread airplane application of DDT. They referred to the diverse life histories and habits of a great variety of insects, the ecological differences in streams, the variation in susceptibility of different species, and the proximity of unaffected waters.

Slack (1955, p. 16) pointed out that pools which persist during periods of discontinuous stream flow act as faunal reservoirs for the repopulation of the stream when flow is resumed. Paloumpis (1956, p. 60) called these pools "stream havens" and concluded (Paloumpis 1958, p. 559) that survival of fish in an intermittent Iowa stream was possible only because such areas remained inhabitable even when severe catastrophes affected the stream as a whole. In Smiths Branch, only two pools remained in such a condition throughout the entire drought period that they would support organisms which generally live in clean, flowing waters, and even in these pools the populations soon became dominated by stagnant-water forms. Such pools serve as faunal reservoirs, but many of their inhabitants may be species unsuited for repopulating the flowing stream.

Neill (1951, p. 765) suggested the interesting possibility that fish may survive drought periods in crayfish burrows. Many crayfish had burrows in moist bottom materials after the flow stopped in Smiths Branch and surface water was gone, but no fish were found in any of the burrows examined.

Extensive urbanization, industrialization, and the use of chemical controls for diseases and pests have been responsible for the destruction of many aquatic populations. The harmful effects may act only temporarily and over only a small area, or they may be continuous, recurring, and damaging over several entire drainage basins. The re-invasion phase of the Smiths Branch study showed the rate of recovery that can be expected when a stream population is destroyed.

The rate of re-invasion of a stream habitat depends on (1) the extent of the area affected, whether a short section of stream or an entire drainage system, (2) the sources of new organisms, such as the abundance of suitable species, the distance to be traveled, and the barriers to be crossed, (3) the degree of damage and recovery of the habitat, for example, continued high biological oxygen demand, sludge accumulations, or traces of harmful repelling chemicals, (4) water levels, and (5) season of the year.

Short sections of streams denuded of aquatic organisms are generally very rapidly repopulated by both invertebrates and fishes. For example, Leonard (1942) and Kennedy (1955) followed the colonization of newly created sections of trout streams. Trout and trout food organisms had established fair populations within three months after the new channels were opened to natural stream waters. Larimore (unpublished data on Jordan Creek in Illinois) removed all the fish from a 1.0-mile section of stream and then found that within three weeks most of the original resident species had re-entered the area. In these studies, and there are other similar observations which could be mentioned, ingression was possible from upstream as well as from downstream.

When a population in an entire watershed is affected, recolonization must be done by

surviving organisms or by organisms that move upstream from lower waters. Motility becomes important. Barriers, such as dams or polluted areas, may inhibit ingression, especially ingression of fish and flightless invertebrates.

Roos (1957) reviewed most of the investigations of stream colonization by insects; he mentioned studies of downstream drifting, positive rheotaxis, and upstream migrations of aquatic insects as functions of invertebrate distribution, and then presented evidence in support of the "colonization cycle" as proposed by Müller (1954). This cycle—the upstream migration of aquatic insects to deposit eggs and then the downstream drifting of the resulting benthic forms—seems to explain much of the recolonization of insects in Smiths Branch. Although we do not know how important the invertebrates surviving in Smiths Branch were in its recolonization, the insects that were at first abundant apparently were from adults that had flown in from other streams.

Repopulation by invertebrates is obviously influenced favorably by the seasonal occurrence of various life stages—emergence of adults, egg laying, developmental periods of immature forms, etc.—at times of favorable water conditions. Stehr and Branson (1938, p. 300) observed that the seasonal stages of the life cycle of many of the animals, especially the insects, was an important factor in determining both the variety and the population size at various seasons in an intermittent Ohio stream. In Smiths Branch the normal life cycles of some of the invertebrates were modified by the adverse conditions associated with the drought.

The rate of ingression of fish into warm-water streams also is affected by the seasons; it is generally most rapid during the spring, at a time of moderately high water, and may be very slow for some species during the summer and winter months.

Katz and Gaufin (1953, p. 164) noticed a winter delay in re-invasion; they found that during the winter fish did not move into a previously unacceptable area of a polluted Ohio stream even though it was then judged to be free of harmful pollution.

We found that fish moved back into Smiths Branch very quickly during April and May, but re-invasion was slow for several weeks during late February and early March after the stream flow was first resumed. Fish had moved into the first few pools above the stream mouth by March 1, but they failed to pass on upstream even after increased stream flow had eliminated the physical barriers. Slow recovery of the fish food supplies was considered, but rejected, as an explanation of this delayed fish ingression. Although many generally important items may be missing from a recently re-established food supply, most stream fishes adjust their feeding habits to utilize a great variety of materials or else may normally feed on materials which are quick to increase, such as bottom ooze or diptera larvae. In discussing the food relationships of several stream minnows, Starrett (1950b, p. 231) pointed out that "the ability of certain fishes to modify their diet to take abundant foods and to compensate for the absence of their usual food items is probably an important factor in regulating the abundance of various species." A shortage of fish food supplies might delay the re-invasion of fish in a stream following a catastrophe if the fish have immediate access to the denuded area or if there is continuing damage to the habitat (e.g., deposits of toxic wastes) which prevents or retards the development of food organisms.

The "colonization cycle" proposed by Müller (op. cit.) for aquatic insects is directly applicable to stream fish. Many of the Smiths Branch species have an upstream spawning run. Some adults of the species move out of the Salt Fork River and upstream in Smiths Branch to spawn, produce a brood of young, and then return downstream after their breeding season. Most of the young gradually shift downstream as they approach maturity; some may remain upstream, where they fill vacancies in the resident small-stream population.

This concept implies that small warm-water streams such as Smiths Branch may be generally inhabited by species composed of two somewhat distinct stocks: one a resident stock that remains year after year and the other a stock of breeding fish that move up from the larger rivers to reproduce in the small streams and return to the larger rivers before midsummer. The resident stock in Smiths Branch was destroyed in 1953. The 1954 brood in Smiths Branch was produced by the transient stock from the Salt Fork River. The work of Funk (1957) in Missouri, from which he proposed that warm-water stream species consist of a sedentary and a mobile group; and of Larimore (1952, and unpublished studies) in Illinois seem to support this concept of distinct fish stocks in small warm-water streams.

Another idea that may or may not contradict

the above concept has arisen through studies by Gerking 1950, 1953, Funk 1957, Larimore 1952, and others in which certain fish have shown a strong attachment to a small area of stream and so move about very little. These studies revealed also that certain individuals of the considered species stray from one place to another during at least part of their lifetimes. Such movement may be very important in repopulating denuded areas, for it was suggested that these straying fish may establish residences where reduced population pressure has reduced competition.

In the Smiths Branch study, we were interested in the natural repopulation of denuded areas. Most of the original species of fishes became re-established after the 1953 destruction, and their relative abundance was roughly similar to that in earlier years. The actual degree of recovery of a stream population seems impossible to determine. The populations are never constant; their numbers and composition change continually. The continual shifting of parts of the population—shifting associated with environment changes, seasons, and life cycles—may account for the rather rapid recovery of the population under observation in this study of Smiths Branch.

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Several members of the Natural History Survey staff helped in the preparation of the manuscript. Drs. Donald F. Hansen, William C. Starrett, and George W. Bennett critically read the entire manuscript, and Dr. Herbert H. Ross read the section dealing with invertebrates. Mr. James S. Ayars gave editorial assistance throughout the preparation of the paper. The photographs were taken by Mr. William E. Clark; the figures were drafted by Miss Marguerite Verley.

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Water Temperature Reduction in Shortened Spring Channels of Southwestern Wisconsin Trout Streams

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ABSTRACT

Late afternoon summer water temperatures at the mouth of a spring channel on a trout stream near La Crosse in southwestern Wisconsin were reduced by 10° to 11° F. by shortening the channel by 67 percent and routing the water through a willow-shaded location.

INTRODUCTION

Since 1955 the Fish Management Division of the Wisconsin Conservation Department has been engaged in a program of stream improvement under the Dingell-Johnson Act on the headwaters of Coon Creek, a small trout stream in southwestern Wisconsin. This headwaters area is sometimes known as Bohemian Valley Creek.

Stream improvement measures on Bohemian Valley Creek have consisted of stabilizing streambanks with rock riprap, seeding grasses on reshaped slopes above the riprap, fencing a strip of land ranging from 50 to 80 feet wide to exclude livestock from the bed of the stream, providing cattle passes at selected places mutually agreeable to the landowner and the Fish Management Division, installing in-channel devices, and encouraging soil- and water-conserving agricultural practices on the farms of the area (Voskuil 1957).

As a supplement to a number of bank stabilizing and habitat improvement measures, an occasional spring channel has been shortened with the aim of reducing the temperature of the water in summer and warming it in the winter as it empties into the stream. Although the most important single factor in reducing stream temperatures may be the shade provided by the natural reseeding of willow, cottonwood, and other tree species, the effect of channel diversion of carefully selected springs of adequate volume seems to warrant study.

This paper gives the results of shortening a spring channel in terms of water temperature reductions at its confluence with the stream.

The authors are indebted to Mr. Lewis Posekany of the Rivers Survey Branch of the Wisconsin Conservation Department for loan of the thermographs used in the study.

THE STUDY AREA

Coon Creek is a small stream about 20 miles long, with headwaters in southwestern Monroe, southeastern La Crosse, and northern Vernon Counties, Wisconsin. The mean air temperature in July is 71° F. and maximum air temperatures have reached 108° according to the U. S. Department of Agriculture Yearbook (1941). The bedrock in the area consists of Lower Magnesian dolomite resting on Upper Cambrian sandstone. Springs are abundant, and their cooling effect is a big factor in trout management in the area.

The spring selected for study is near the center of section 23, T. 15 N., R. 5 W., in southeastern La Crosse County. This spring had a constant flow of 37 gallons per minute during the entire study period. It meandered through an open sun-exposed pasture in a watercress-filled channel nearly parallel to Bohemian Valley Creek for a distance of 563 feet before entering the stream. At this point the stream had a mean flow of about 10 cubic feet per second during the study period.

[1]Lake States Forest Experiment Station, U. S. Department of Agriculture, Forest Service, maintained at St. Paul 1, Minnesota in cooperation with the University of Minnesota.

[2]Wisconsin Conservation Department, Fish Management Division, Black River Falls, Wisconsin.

MATERIALS AND METHODS

A three-pen recorder was placed near the intersection of the spring channel and the creek. One element recorded air temperature in the shade, a second recorded water temperature near the mouth of the spring channel, and the third recorded the temperature of Coon Creek about 20 feet upstream from the intersection of the spring channel and the creek. The three-pen recorder was operated at this Station from August 22 to August 28, 1957.

At the point in Bohemian Valley Creek where the relocated spring channel was to be cut through at a later date, stream temperatures were read with a glass stem thermometer. These were identical to those at the original confluence point before diversion.

A single-pen thermograph recorded temperature of the spring where it first emerged from the ground during the entire study period.

On August 28 a new channel 186 feet long (67 percent shorter than the natural channel) was cut from the spring on a straight line to the creek with a small bulldozer. The banks of the new channel were immediately seeded to a grass-clover mixture to hold soil movement to a minimum. About 90 percent of the length of the new channel was shaded by 15- to 20-foot-high willows.

The three-pen thermograph was then moved to the mouth of the newly constructed spring channel where it entered Bohemian Valley Creek and operated there from August 28 to September 22.

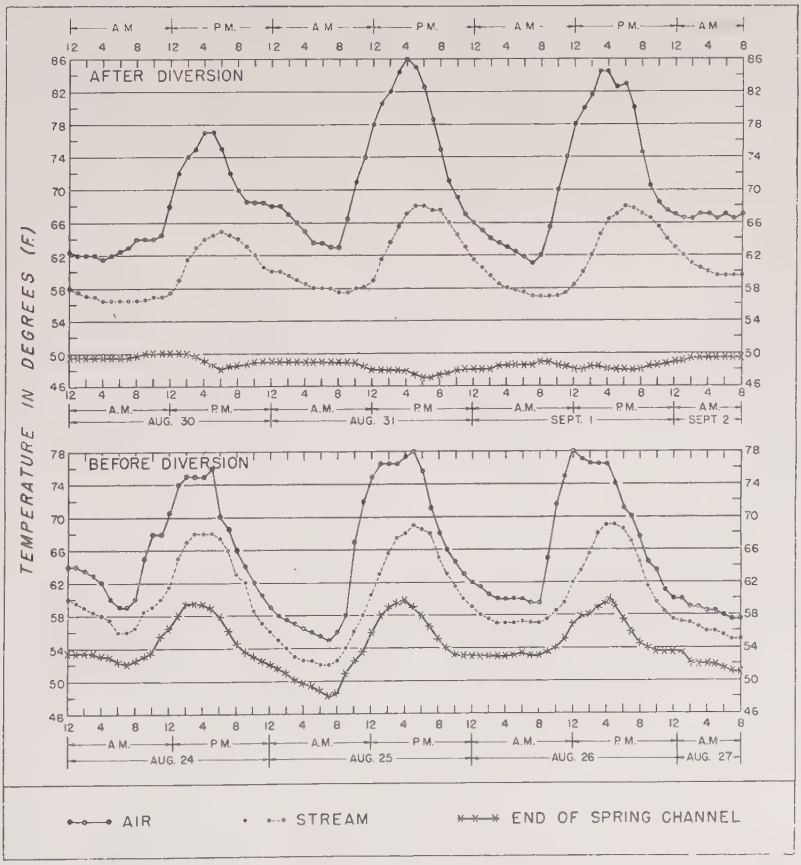

FIGURE 1.—Temperature regime before and after shortening of a spring channel flowing into a trout stream.

RESULTS OF THE STUDY

For purposes of comparison, the record for the two most comparable 3-day periods are reproduced in Figure 1—one period before diversion and another period after diversion of the spring channel. The temperature of the spring where it emerged from the ground is not reproduced because it remained virtually the same during the entire period—averaging 48° F. with a maximum variation of about 1° F.

Although air temperatures in the period after diversion were slightly higher than in the period before diversion, the maximum stream temperatures, deemed a better index of total intake of solar radiation than air temperature, are very similar.

On a moderately warm day when peak stream temperatures of 68° F. were reached at 4 to 5 p.m., the temperature at the end of the spring channel reached 60° before channel shortening, and after shortening it remained at 50° or less, averaging 49°. This represents a 10° to 11° lowering of temperature at the mouth of the spring channel. It is probable that even greater contrasts would occur on extremely hot days.

The benefits in terms of water temperature amelioration are attributed to the combined effect of a shorter debris-free channel, increased velocity of flow, and shade from the willows. Seepage losses were not increased in the newly created channel. This, of course, must be recognized as a potential hazard in any spring channel diversion.

The shortened channel also appears to have had an ameliorative effect on the stream temperature itself in winter months. For instance, on Feb. 7, 1958, temperatures were taken across Coon Creek, 5 yards below the confluence of the spring channel and the creek. The general temperature was 37° F. in most of the stream cross-section (about 8 feet wide) with a sudden increase of 5° F. in a band about 1.5 feet wide affected by spring water, and then a drop back to 37° F.

Spring diversion should receive further studies, especially where the water can be directed into deep shaded pools; in such pools cold water may stratify at greater depths so that trout could survive in periods of summer heat.

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Infectious Nature of Pancreatic Necrosis

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ABSTRACT

To determine if pancreatic necrosis is a communicable disease of trout, lots of eyed brook trout eggs were obtained from four hatcheries. Pancreatic necrosis appeared spontaneously in trout from one of these hatcheries and the other strains were exposed to infection by suspension prepared from diseased fish. In all cases, typical pancreatic necrosis appeared in fish exposed to infection and the control fish remained healthy. Disease was more acute in fry fed brine shrimp nauplii than in those fed beef liver. Mortality data suggest that susceptibility to pancreatic necrosis decreases with the increased age of trout. No treatment for the disease is known, but sanitary measures were effective in preventing its spread.

INTRODUCTION

Infectious pancreatic necrosis was first described by M'Gonigle (1941) as an "acute catarrhal enteritis" in very young brook trout (*Salvelinus fontinalis*). It is an acute disease of salmonid fishes, and of brook trout in particular. Its characteristic symptoms are violent whirling and horizontal corkscrewing. After each attack fish sink to the bottom. The largest and finest fingerlings become affected most acutely. The intestine is usually free from food, but distended with clear and colorless mucus. Pancreatic tissue is necrotic and frequently hyaline degeneration of striated muscle can be detected. Losses as high as 70 percent are not uncommon among fingerling trout which are only several weeks old. Observations presented by Wood, Snieszko, and Yasutake (1957) justified formulation, of a hypothesis, here tested, that pancreatic necrosis is an infectious disease. Although it remains to be demonstrated, there is strong evidence that a virus may be the cause of the disease.

The first recognized outbreak of pancreatic necrosis at the Leetown experimental hatchery occurred in fingerling brook trout in January 1953. It coincided with the first introduction of eyed brook trout eggs from a hatchery at Bellefonte, Pennsylvania. Green eggs from the Bellefonte hatchery were transferred to the Federal hatchery at Lamar, Pennsylvania, where they were incubated until eyed, and then shipped to Leetown. From that year to the present (1958) brook trout at the Leetown station were hatched from eyed eggs received from hatcheries in Berlin, New Hampshire; Bellefonte, Pennsylvania; and Beaver Creek, Maryland. Whenever the Bellefonte trout were present and reached the feeding stage, infectious pancreatic necrosis appeared first among these fish and later appeared in brook trout of similar age which hatched at Leetown from eggs received from other sources. This disease has never been observed at Leetown among brown trout (*Salmo trutta*) or rainbow trout (*Salmo gairdneri*) of similar age, or older, which were kept in adjacent troughs. Experiments described in this paper were performed in order to test the validity of the hypothesis that pancreatic necrosis is a communicable disease of brook trout.

Materials and methods

All experiments were carried out in stainless steel experimental troughs having dimensions of 53 by 15 by 12 inches. The temperature of spring water used was 12 to 13° C. (53 to 55° F.) Brook trout eggs in the "eyed" stage were used. After disinfection of the eggs in a solution of sulfomerthiolate—1:5000 for ten minutes—they were placed in a single layer on hatching trays and incubated in flowing water. To protect eggs from fungus infection they were treated daily by flushing with a malachite green solution. Strict sanitary measures were observed during the entire period of experiments, which continued through April, 1958, to prevent accidental spreading of the disease among the trout which served as controls. Sources of eggs, hatching dates and other pertinent information are presented in Table 1.

[1]Trainees at the Eastern Fish Disease Laboratory, from October 1, 1957 to July 30, 1958.

Blue-sac disease appeared in all lots of sac-fry and highest losses occurred in trout from Berlin, New Hampshire, and Walhalla, South Carolina, and the lowest in the Beaver Creek, Maryland trout. It has been suggested to us[1] that whirling or corkscrewing, which is one of the signs of pancreatic necrosis, might be due to iodine deficiency. Therefore, some of the experimental trout were fed beef liver enriched with traces of iodine in form of Lugol's solution or by addition of Cytomel[2] (synthetic L-triiodothyrinine). Other lots of experimental trout were fed nauplii of brine shrimp (*Artemia gracilis*) because recent trials have shown that this diet was superior to standard hatchery diets for some salmonid fishes during their first weeks of feeding (Hales and Bangster, 1956; Coates, Ellis and Schwab, 1957).

Pancreatic necrosis appeared spontaneously in the Bellefonte trout. Trout obtained from other sources were exposed to infection by adding to the water at feeding time aqueous suspension prepared from several, entire, Bellefonte trout showing symptoms of this disease, and from several frozen trout left from the last year experiments. Mortalities were removed from the troughs daily and sick or dead fish were spot checked for the presence of the symptoms characteristic for this disease.

[1]Private communication from J. R. Dick, D.V.M., Fort Dodge Laboratories, Fort Dodge, Iowa.

[2]Cytomel (synthetic L-triiodothyronine) was received free of charge through the courtesy of S. F. Scheidy, D.V.M. from Smith, Kline and French Laboratories in Philadelphia, Pennsylvania.

EXPERIMENTS AND RESULTS

The design of the experiment was somewhat changed with each strain of brook trout; therefore the results will be described separately for each experiment.

1.—*Bellefonte brook trout.* When fry were old enough to begin feeding they were distributed by 75 gram aliquots among eight troughs. Trout in each of the four pairs of randomly selected troughs received one of the following diets: A.—Finely ground beef liver; B.—The same, enriched with 25 micrograms of Cytomel per daily food allowance; C.—The same, enriched with 5 drops of Lugol's solution per daily food allowance; and D.—Freshly hatched nauplii of brine shrimp. Fry were fed 4 or 5 times daily.

Pancreatic necrosis appeared spontaneously within a week. The mortalities which were calculated as percentages of residual live fish at beginning of each 5-day period starting on December 24, are presented in Figure 1. The disease had a more acute course and caused highest mortalities in fry that were fed brine shrimp. Differences in mortalities between the other diets were insignificant. On January 22 all fry were weighed and counted. Following are average weights gained by fry on the different diets in milligrams: brine shrimp 137; iodine 108; Cytomel 95; liver 73. Diet consisting of brine shrimp strongly influenced gain in weight, and iodine in two forms slightly influenced gain in weight. The disease had run its acute stage within a month and a Bellefonte fry were then transferred to the liver diet with small addition of brine shrimp and kept under extended observation.

TABLE 1.—*Sources and handling of brook trout eggs and fry used in experiments on pancreatic necrosis experiments*

	Bellefonte, Pennsylvania	Beaver Creek Maryland	Berlin, New Hampshire	Walhalla, South Carolina
Eggs received	Nov. 19, 1957	Nov. 25, 1957	Nov. 27, 1957	Nov. 28, 1957
Hatching completed	Dec. 5, 1957	Dec. 3, 1957	Dec. 16, 1957	Dec. 18, 1957
Distribution to experimental troughs and start of feeding	Dec. 23, 1957	Dec. 22, 1957[1]	Jan. 9, 1958	Jan. 9, 1958
Exposed to infection	Jan. 1, 1958 (Spontaneous outbreak)	Jan. 2, 1958	Jan. 21, 1958	Jan. 21, 1958

[1]The second experiment with the Beaver Creek trout was started on January 23 and the third on Mar 20. 1958.

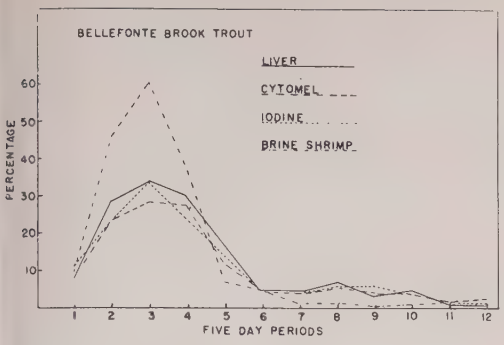

FIGURE 1.—Mortalities (expressed as percentages on the "Y" axis) in a spontaneous outbreak of pancreatic necrosis in brook trout fry from Bellefonte, Pennsylvania and the effect of modified diets.

2. *Beaver Creek, Maryland, brook trout.* Three infection experiments were performed with this Maryland strain. In each succeeding experiment older trout from the same lot were used in order to determine the effect, if any of the age on the susceptibility to pancreatic necrosis.

A.—In the first experiment trout fry were separated into four 150 gram aliquots of 1330 to 1590 fish per trough and in a few days were exposed to infection in half of the troughs. Trout in two troughs, one infected and one control, were fed liver and in the other two troughs were fed brine shrimp.

In this experiment the trout, which originally were free from pancreatic necrosis, responded very clearly to infection (Figure 2). The course of infection was more acute for trout fed brine shrimp. Upon subtracting the number of mortalities in controls, losses which could be attributed to pancreatic necrosis were 41 percent in the trout fed beef liver and 48 percent in those fed brine shrimp. Most of relatively high mortalities in the control trout was attributed to blue-sac disease. At the end of the experiment, the average weight of the trout on brine shrimp diet was 179 milligrams per fry and those on the liver diet was 185 milligrams. This small weight difference was not considered significant.

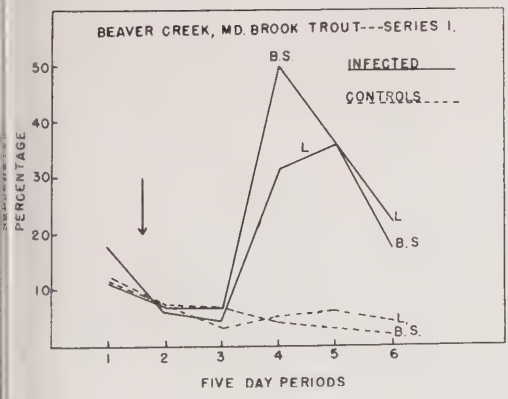

FIGURE 2.—Mortalities (expressed as percentages on the "Y" axis) from pancreatic necrosis induced in brook trout fry from Berlin, New Hampshire by exposure to infection (arrow); fry fed brine shrimp larvae.

B.—The second experiment with Beaver Creek trout was started on January 23 and continued for 30 days. Fish used in this experiment served as uninfected controls in the first experiment. Trout from the two control troughs were mixed together and distributed in lots of 240 to 250 fish in each of four troughs. Trout in two troughs served as controls and those in the other two troughs were exposed to infection, the source of which was a frozen diseased trout from the first phase (part A) of work with this strain. Fish in all troughs were fed the same diet, 3 or 4 feedings a day of ground beef liver interspersed with 1 or 2 feedings of brine shrimp. Results were very similar to those obtained in the first experiment. Six weeks after this experiment was started the cumulative mortalities in the controls were 7 percent and in the infected fish were 44 percent.

C.—The third experiment with the same lot of Beaver Creek trout was performed from March 20 to April 29. Fish which served as controls in the second experiment were evenly divided among four troughs. Trout in two troughs were infected in the same manner as before, and those in the other two served as controls. Unfortunately this experiment became complicated by gas-bubble disease (pop-eye) which caused quite high mortalities. At the end of the experiment the total losses were 30 and 31 percent in the infected fish and 20 and 27 percent in the controls. Mortalities which might be attributed to pancreatic necrosis in this case were approximately 7 percent.

3. *Brook trout from Berlin, New Hampshire.* During hatching time and the sac-fry stage there was a great loss from blue-sac disease. From about 15,000 eggs received, only about 2,000 fry survived to the start of the experiment and all together weighed only 165 grams. Fry were distributed in 20 gram quantities among eight experimental troughs each holding, on the average, about 320 trout. Trout in four troughs were infected and those in the other four troughs served as controls. Trout in

two troughs in each group received beef liver, and in the other two were fed with brine shrimp.

For trout fry on beef liver diet mortalities in controls were 75.5 percent and in infected trout 79.5 percent. For those fed brine shrimp, however, total losses in infected fish were 91 percent and only 51.5 percent in controls (Figure 3). In the group fed brine shrimp (controls and infected) growth of all trout was uniform and the general appearance of the fish excellent. Among the fish fed liver there were many stunted individuals which took no food, slowly wasted away, and died. These made up most of the high mortalities of fish fed on liver. On the basis of the data obtained from fry fed brine shrimp, mortalities attributable to pancreatic necrosis were 40 percent; about the same as that estimated for fry of similar age received from other hatcheries.

4. *Brook trout from Walhalla, South Carolina.* During the incubation period many eggs were lost from "white spot" and many of the sac fry died from blue-sac disease. The remaining fry were distributed in aliquots of 65 grams or about 1000 fish to each of the four troughs. One half served as controls and the other was exposed to infection in the manner previously described. During 40 days from the date of infection 30.5 percent of trout in the control lots died and 68 percent in infected troughs. The results of this experiment demonstrated again the infectious nature of pancreatic necrosis. Here losses attributable to this disease were near 40 percent.

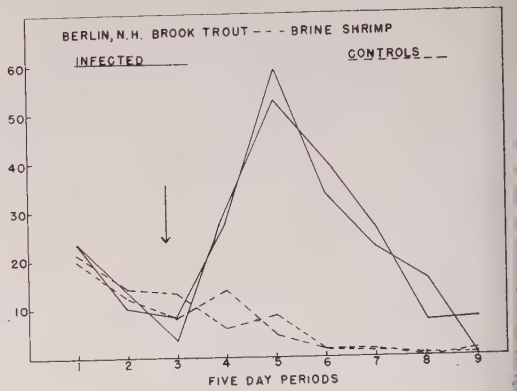

FIGURE 3.—Mortalities (expressed as percentages on the "Y" axis) from pancreatic necrosis induced in brook trout fry from Beaver Creek, Md. by exposure to infection (arrow); fry fed either brine shrimp (B.S.) or beef liver (L).

DISCUSSION

From the results presented it can be concluded that pancreatic necrosis is an infectious disease. Experiments on the nature of the pathogen that are in progress suggest that it is caused by a virus.

From the observations made with the Beaver Creek trout, it can be tentatively assumed that the losses caused by this disease tend to decrease as the age of brook trout fingerlings increases. If the age of fingerlings is plotted on one coordinate, and the mortalities attributed to pancreatic necrosis on the other, a nearly straight line is obtained. If correct conclusions can be based on such data, brook trout five months old, or older should suffer no significant losses from pancreatic necrosis. Further experiments will be needed, however, to test the validity of this hypothesis. Some virus diseases, in particular infections caused by the Coxsackie group of viruses, are acute and cause high mortality only in young animals. On the basis of the observation that juvenile trout are most susceptible, and on the basis of histopathological findings, Snieszko, Wood, and Yasutake (1957) state that there is a "possibility that a relationship exists between the causative agent of this disease and the viruses of the Coxsackie group."

There is a relationship between the losses caused by pancreatic necrosis and diet of trout. In general, higher losses occurred among trout fed brine shrimp than those feed beef liver. In our experiment with brook trout fry from Berlin, New Hampshire, we have confirmed the observation made by Coates, *et al.* (1957) and Hales and Bangster (1956) that brine shrimp is a very valuable diet for fry of some salmonid fishes. The fact that higher mortalities from pancreatic necrosis occurred in fry fed brine shrimp is apparently in agreement with the observation that pathogenic viruses tend to cause more acute disease symptoms and higher mortality among well-fed hosts. As remarked by Wilson and Miles (1955) " . . . viruses, which are highly adapted intracellular parasites, may be peculiar in requiring the full health of the host's susceptible cells for their proliferation". Addition of traces of iodine or a synthetic thyroid hormone had no significant effect on the course of pancreatic necrosis in Bellefonte brook trout with which these substances have been tested.

At the Leetown station the outbreak of pancreatic necrosis occurred only in brook trout. We have seen, however, at other hatcheries outbreaks of an identical or very similar disease

among fingerling brown trout and small fingerlings of Atlantic salmon (*Salmo salar salar*).

It is also evident from these experiments that while this disease is very contagious, its transmission among brook trout fry at a fish hatchery can be prevented by strict sanitation. We were able for months to maintain the control trout free from the symptoms of this disease in troughs adjacent to diseased fish by performing all operations with hands covered with disinfected rubber gloves and by decontaminating all utensils by immersion in solutions of sodium hypochlorite or Roccal, (a solution of alkyl dimethylbenzylammonium chloride).

It should be added here that no specific treatment for this fish disease has been tried. If it is, as it seems to be, a true virus disease, it is not likely that a treatment will be available in the forseeable future, unless a break-through is made in the general therapy of virus diseases. The only recommendation which can be given at this time is to avoid brook trout eggs from hatcheries which, on the basis of previous experience, can be suspected as a source of the pathogen causing this disease.

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Studies of the Life History of the Blue Crab (Callinectes sapidus Rathbun) in Louisiana Waters

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ABSTRACT

Analysis of 133 plankton, 462 otter trawl, and 124 shore seine samples from Lake Pontchartrain and adjacent waters of southeastern Louisiana suggests the following pattern for the life history of the blue crab in the area, although details are in need of confirmation. Mating takes place in the fresher areas followed by migration of the mated females to more saline waters. After hatching the young migrate in toward the estuaries where most of the growth takes place. The first wave of young seems to arrive in Lake Pontchartrain in May, and crabs spawned in the spring appear to reach a size of about 65 mm. by September of the first year. The relative absence of adults from winter collections suggests migration or hibernation. Food habits, parasites, and periodicity are discussed.

INTRODUCTION

The life history of the blue crab, *Callinectes sapidus* Rathbun, has been extensively investigated in Chesapeake Bay, and outstanding studies relating to this area have been published by Hay (1905), Churchill (1919, 1942), Truitt (1939), and Van Engel (1958). Details of the literature pertaining to the species in Chesapeake Bay and related areas of the South Atlantic coast may be obtained from the bibliographies of these papers. During the past several years a number of works have appeared treating various aspects of the life history of the species on the northern coast of the Gulf of Mexico. Significant among these are the reports of Daugherty (1952), Gunter (1950), Hedgpeth (1950), Hildebrand (1954), and Reid (1955, 1956) which concern the ecology of the species in the estuaries and Gulf waters of Texas. In Louisiana the blue crab populations have received attention of workers in a number of fields, including the following: commercial and sport fishery (Benedict, 1940; Gowanloch, 1952) food habits (Darnell, 1958), general ecology and distribution (Behre, 1950; Gunter, 1938; Humes, 1942; Viosca, 1938, 1953), oyster predation (Menzel and Hopkins, 1956), parasites (Humes, 1941, 1942), and physiology (Fingerman, 1955a, b; May, 1936). Most of the published information pertaining to the Louisiana populations, however, relates only indirectly to the life history of the species, and, although the Louisiana estuaries constitute one of the major centers of commercial production of the blue crab in this country, the life history and dynamics of the populations inhabiting the area are virtually unknown.

Consideration of the Louisiana populations will be greatly facilitated by an understanding of the life history as worked out in the Chesapeake Bay area. Pertinent features of this life history (particularly as discussed by Churchill, 1942, and Van Engel, 1958) are summarized below.

1. Eggs hatch near the mouth of the bay in moderately saline waters (over 20 *per mille*).
2. Larval stages (up to the megalops) are passed in about one month.
3. The young crabs migrate up the bay to fresher and shallower areas where most of the feeding and growth take place.
4. From eight to twelve growing months are required for a crab to pass from the egg to the adult stage.
5. Growth ceases during the winter months and is resumed during late April or early May.
6. Since growth does not occur during the winter, from twelve to eighteen months are involved from the time of egg deposition until mating occurs.
7. Mating takes place in the fresher areas. Following copulation the adult males remain in these fresher areas, but the mated females migrate back to the more saline waters, where spawning and hatching of the eggs take place.
8. The bulk of the young crabs hatch in June and early July, although a second peak may occur in August.

METHODS

During the course of an ecological survey of Lake Pontchartrain and adjacent waters of southeastern Louisiana (July, 1953—June, 1955), information was obtained regarding the local plankton, invertebrate, and fish populations, and much of this information relates directly to the life history of the blue crab. Because of the unusual complexity of this life history, many of the present conclusions must be considered tentative. The study should serve, however, to guide future research into the dynamics of the populations of this important crustacean.

Most of the blue crab samples discussed herein were obtained from Lake Pontchartrain proper. The general hydrographic conditions of this estuary have been considered elsewhere (Darnell, 1958). It is important to note here that the lake is characterized by low salinity (generally less than 8 0/00), and that water temperatures vary from a winter low of around 10°C. to a summer high of about 30°C. On the basis of the low salinity conditions it would be assumed that, if the Louisiana populations are similar to those of Chesapeake Bay, only a portion of the life history should occur in these "inside" waters. Two collecting trips were made to adjacent "outside" waters of Lake Borgne and the Chandeleur Sound where higher salinities (up to 35 0/00) were encountered, and these collections provide important supplementary data regarding the life history of the species.

The Lake Pontchartrain data are based primarily upon collections made at regular stations throughout the lake (see Figure 1). These were sampled in comparable fashion at monthly intervals over a period of almost two

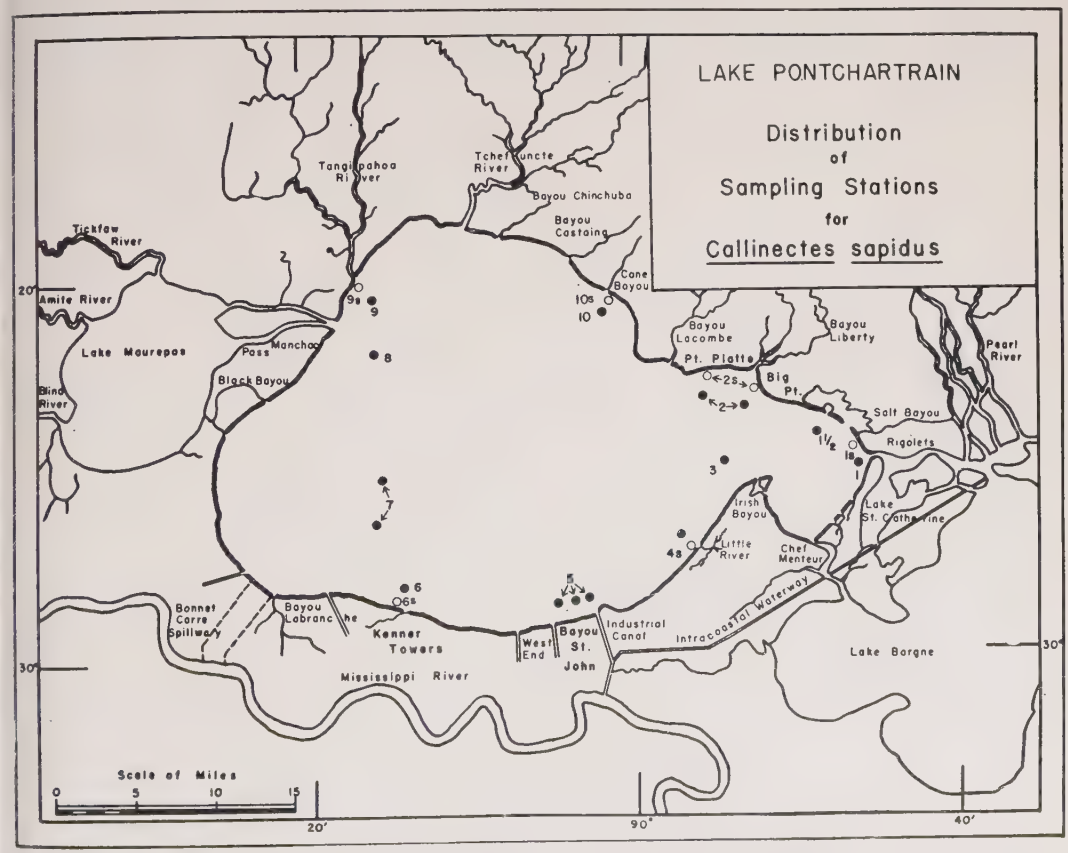

FIGURE 1.—Distribution of regular monthly sampling stations for trawls and seines in Lake Pontchartrain (1953-1955). Seine samples are designated by open circles and the letter "s". The sampling station indicated by a fraction represents the exploratory station referred to in Figure 6.

years (for details of procedure see Darnell, 1954). Standard collecting gear included otter trawls (mainly three-quarter inch mesh) in waters deeper than six feet, and shore seines (one-quarter inch and one-half inch mesh) in marginal waters four feet or less in depth. Quantitative plankton samples were obtained with a Clarke-Bumpus sampler employing nets of number ten mesh, and non-quantitative samples were taken with a Wisconsin tow net with number twenty mesh.

In addition to the regular monthly collections, many other sporadic or "exploratory" samples were taken which together provide much supplementary data. The analyses presented in the present paper are based primarily upon comparable data, and any deviations are noted in the text. Most size measurements were accomplished in the field upon live crabs, using fish measuring boards. The standard size measurement used throughout the study is "carapace width", i.e., the distance between the tips of the lateral spines. The validity of this statistic as a measure of growth has been pointed out by Gray and Newcombe (1938) and others.

RESULTS

Seasonal occurrence of crab larvae

In waters of southeastern Louisiana occur many species of crabs whose larvae might appear in the plankton samples. During the survey the following species were collected from the waters or shores of Lake Pontchartrain itself, portunid crabs (*Callinectes sapidus*), xanthid crabs (*Eurypanopeus depressus, Rithropanopeus harrisii,* and probably *Panopeus herbstii*), grapsoid crabs (*Sesarma reticulatum*), ocypodid crabs (*Uca* sp., probably *U. mordax*), and majid crabs (*Libinia erinacea*). Only two of these species were at all abundant within the lake, the blue crab (*C. sapidus*) and the mud crab (*R. harrisii*). Outside of Lake Pontchartrain other species were collected, including other portunid crabs, but none of these appeared to be abundant in waters connected with the lake.

Unfortunately, at the time of the original quantitative plankton counts the pertinent literature was not available, and no distinction was made between the different types of crab larvae. Subsequent examination of the monthly non-quantitative plankton tow samples reveals that at least two different species of crab larvae were present in the samples. Larvae of one species (which may have been *R. harrisii*) were widespread and abundant in April and May of both years and were found in some numbers in very low salinities (less than 2 0/00). During late spring and throughout the summer, however, larvae were occasionally encountered which appeared to be identical with those of the blue crab as described by Hopkins (1943, 1944) and by Sandoz and Hopkins (1944). Such larvae were generally obtained in surface tows taken near the salt water passes at times when inflowing currents and bottom roiling could be demonstrated.

Due to the disturbing action of the wind and water currents acting on the bottom of this shallow lake, benthic forms frequently appeared in the surface plankton samples. Since larvae of the blue crab were never abundant in these surface tows, it may be concluded that this species does not regularly spawn inside Lake Pontchartrain. The occasional appearance of apparent blue crab larvae suggests that the species probably does spawn not far away in the more saline environments of Lake Borgne and Chandeleur Sound. Whereas some apparent blue crab larvae appeared during the late spring and through the summer months, seasonal details of the spawning cannot be deduced from the plankton data.

Location of spawning areas

As mentioned above, Lake Pontchartrain is a relatively fresh estuary, and for this reason not all of the stages of the blue crab life history would be expected to occur within its confines. Specifically, it would be anticipated that, following copulation, the mated females would pass out into Lake Borgne and from there to Mississippi Sound or Chandeleur Sound until hydrographic conditions favorable for early larval development were reached (i.e. a temperature range of approximately 20-29°C. and a salinity range of 21-28 0/00 for Chesapeake Bay crabs, according to Sandoz and Rogers, 1944). After hatching and larval development the young crabs would commence their inward migration to fresher areas including Lake Pontchartrain. Specific proof of the postulated migration pattern would rest in a tagging program, but partial proof might be obtained from circumstantial evidence such as the following.

1. Disappearance of most of the adult females from Lake Pontchartrain some time before the peak appearance of larvae and young. This might be manifested as a disturbance in the sex ratio of adult crabs remaining within the lake, resulting in a great numerical preponderance of adult males.

2. Virtual or complete absence of ovigerous females from the extensive Lake Pontchartrain trawl and seine collections.

3. Appearance of ovigerous females in abundance outside of the lake in connected waters of the appropriate salinity.

All three types of evidence were, in fact, obtained. Clasping pairs of adult blue crabs were frequently observed, but due to the pressure of other work, records of such observations were not kept regularly. Several observations were recorded from May, August, and September which tend to bear out Benedict's (1940) statement that in Louisiana waters the primary mating seasons are May and September. Examination of the annual progression of sex ratios of adult blue crabs taken from Lake Pontchartrain (Figure 2) reveals that during June and July the sex ratio was approximately equal but that during all other months the adult population was made up predominately of males. Adult females were conspicuously absent in February and March (two or three months before the appearance of the spring young) and again in August and September (suggesting a second period of spawning). The relative scarcity of adult females from the winter collections might indicate that many of these individuals pass the winter in the warmer, more saline areas outside the lake, although the possibility of hibernation within the lake by adults of either sex is not precluded.

Throughout the period of study a total of one thousand sixteen adult blue crabs were collected from Lake Pontchartrain, of which three hundred and fifty-four were adult females. Ovigerous females appeared in only two of these "inside" collections, one from mid-August, the other from September. These two collections were made at the exit to Lake Borgne, and both probably represent the interception of females in exodus. Out of twenty-eight adult females in these collections, eight bore egg masses ("sponges" or "berries"), all of which were yellow, indicating that they had only recently been produced.

By contrast, two brief collecting trips were

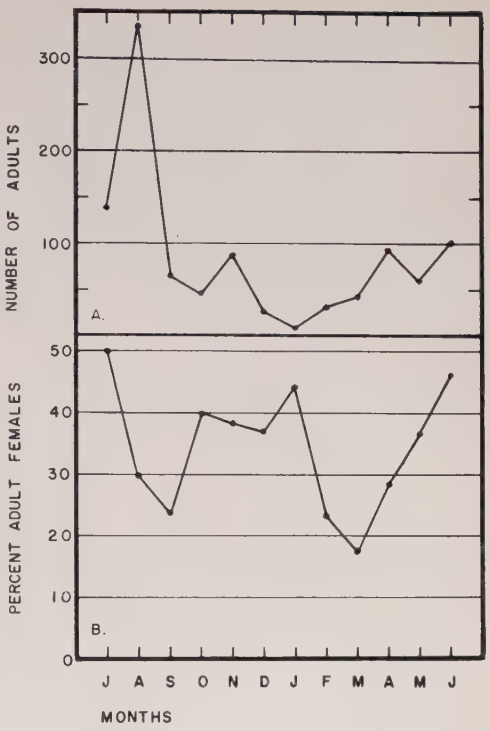

FIGURE 2.— Seasonal progression of sample size and sex ratio of adult blue crabs from Lake Pontchartrain.

made outside of Lake Pontchartrain into Lake Borgne and Chandeleur Sound, one in late March, the other in late August of 1954. During the March trip thirty adult females were captured, of which twenty-six were ovigerous. During the August trip twenty-one were taken, including nine which were ovigerous. These females captured outside the lake bore "sponges" which varied in color from orange to dark brown, indicative of more mature embryos. Ovigerous females encountered outside of Lake Pontchartrain were collected from waters which were warm (19.2-30.0° C.), moderately saline (19.2-31.5 0/00), and of variable depth (8-60 ft.). These collections were obtained from various parts of Lake Borgne (Rigolets, Grand Island Pass, Petit Pass), from Cat Island Channel, and from Chandeleur Sound in the vicinity of Mitchell Island and Mitchell Key.

These data substantiate the conclusions reached in the plankton study and suggest that following copulation the females leave the lake and remain in outside waters at least until the larvae are released. It remains to be in-

vestigated whether or not these adult females re-enter the lake and whether or not repeated spawning takes place in Louisiana, as it does in the Chesapeake Bay area. Hard (1942) has demonstrated that the reproductive history of the adult females may be reconstructed from examination of the gonads and swimmerets, and Humes (1942) and Hopkins (1947) have pointed out the significance of nemertean parasites as further indicators of the reproductive history.

Growth

Reliable information on the growth of estuarine crustaceans, such as the blue crab, is particularly difficult to obtain. In the first place, growth of individual crustaceans is stepwise, and techniques which are readily employed in the analysis of continuously growing animals may not be directly applicable. If the samples are sufficiently large and if the individuals are molting randomly, rather than in phase with each other, this factor may be relatively unimportant. In this event the curve for increase in size should be rather continuous for the group as a whole.

The second source of difficulty lies in the fact that during the long spawning season successive waves of different instars may appear in the estuaries. As the individuals undergo their complex patterns of migration the dif-

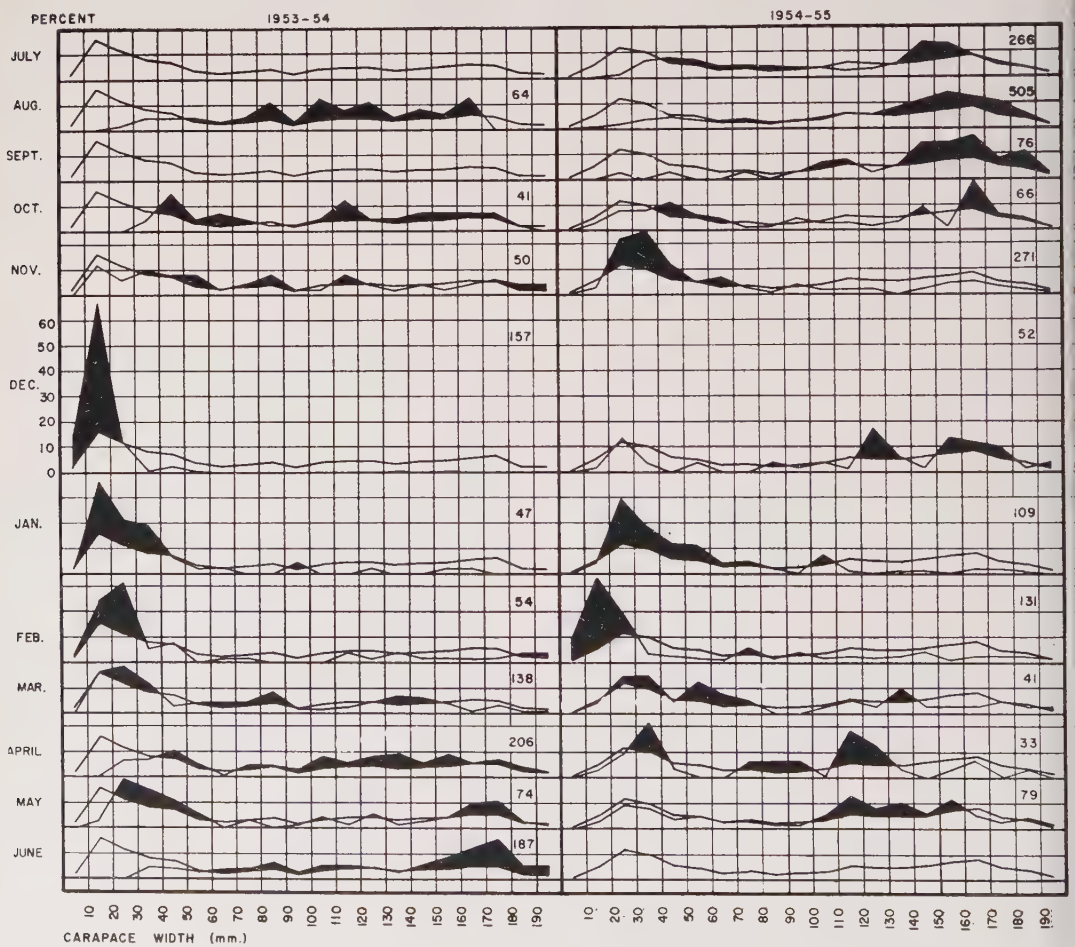

FIGURE 3.—Size-frequency distributions (in percentage) of blue crabs taken from Lake Pontchartrain in trawls with three-quarter inch bar mesh. The size of the sample is indicated to the right of each monthly curve.

ferent waves are seldom distinguishable from one another, and repeated sampling at a single station could lead to entirely erroneous conclusions regarding growth. Analysis of data representing samples taken from several stations throughout Lake Pontchartrain should minimize, but not eliminate, the error due to this factor.

The third source of difficulty stems from the fact that different stages of the life history of certain estuarine crustaceans, notably the blue crab, utilize different habitats. These habitats must be sampled with different types of gear, each of which can be expected to reveal only a portion of the life history. The most complete picture of the blue crab populations in Lake Pontchartrain should be achieved by properly combining the results of the extensive trawl and seine collections made throughout the lake. Previous knowledge of the relative importance of each phase of the life history and of the relative sampling efficiencies of each type of gear would be necessary for any detailed interpretation of such combined data.

In the present discussion the distribution of size classes in the monthly trawl and seine samples will be examined separately. Monthly progressions in size class modes will be noted as possible indications of growth (for a discussion of this procedure as applied to a marine fish, see Moore, 1951). For the reasons listed above and in the absence of supplementary information from growth-pen or tagging studies, conclusions regarding growth are tentative.

The trawl data reveal that, with minor differences, there is a general correspondence of the monthly size compositions for the two years (Figure 3). The frequency of adults in the trawl collections was low during the winter months, and higher during the summer, while the young displayed the reverse pattern. The virtual disappearance of adults from the winter collections may be due to

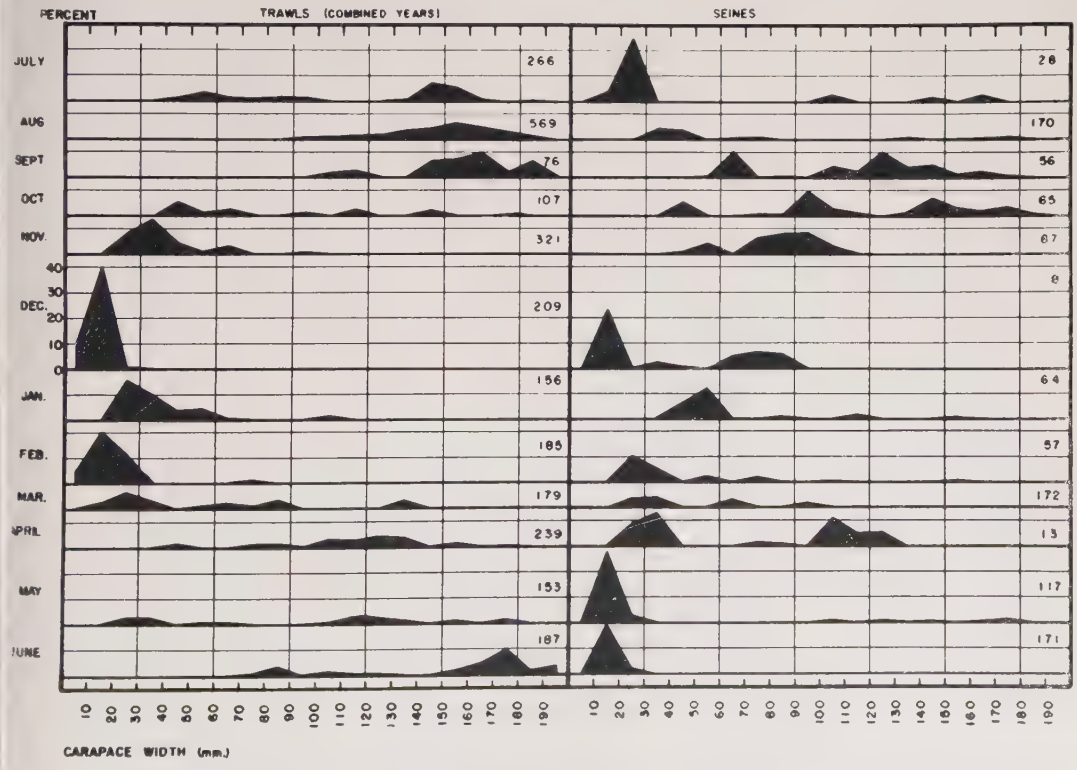

FIGURE 4.—Deviations of monthly frequency distribution from the mean monthly frequency distribution (in percentage). Trawl frequency distributions represent the combined data for the two year period (1953-54 and 1954-55). Seine data represent a single year (1953-54).

hibernation (or migration). The relative absence of young crabs from summer trawl collections suggests that during the warmer months the young crabs move into shallower waters, where they are unavailable to the trawls. In the absence of winter recruitment the gradual increase in modal size of the relatively homogeneous population during the 1953-54 season (December-March) may be suggestive of limited winter growth. During the second winter the salinity of the lake was somewhat higher than during the first winter, and the significance of data from this period is not clear. Acceleration of growth before the influx of a new wave of young seems to be indicated in the spring of both years. In order to summarize the annual picture the monthly trawl data for the two years were averaged, equal weight being given to the data from each year (Figure 4, columns on left). This procedure reduces the magnitude of details and provides a clearer overall picture of the portion of the blue crab population inhabiting the deeper waters of the lake throughout the year.

Seine data represent a single year (1953-54) since seining was not carried out on a regular basis during the second year of the study. These data (Figure 4, columns on right) tend to substantiate the conclusions reached on the basis of the trawl samples, and again a suggestion of limited winter growth may be noted. According to the seine samples major spring recruitment of young crabs took place in May, June, and early July and seems to have fallen to a low level during the hottest summer months with a second burst of recruitment occurring in late fall. Summer growth rates of young crabs are uncertain, but from the seine data it appears likely that spring-spawned individuals averaging 15 mm. in June, and 25 mm. in July, had reached a size of 65 mm. by September. During the summer months a number of blue crabs were taken which measured over 190 mm., and the largest was a 210 mm. male. If the growth rates indicated above are approximately correct, such large individuals must have made use of at least two full growing seasons.

A composite picture of the total blue crab population in Lake Pontchartrain is represented in Figure 5 which was constructed by combining the trawl and seine data. This procedure is based upon the knowledge that the juvenile and adult history is passed partly in the shallow and partly in the deeper waters. Without special knowledge for proceeding otherwise, equal weight is given to the shallow and deeper water portions of this life history. Population growth characteristics as discussed above are apparent in the combined data.

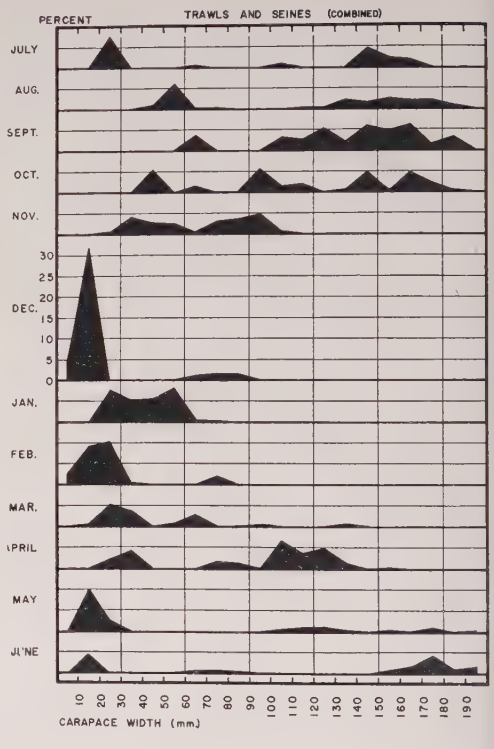

FIGURE 5.—Deviations of monthly frequency distribution from the mean monthly frequency distribution (in percentage) for combined seine and trawl data. In the preparation of this figure each type of gear has been given equal weight.

Patterns of distribution within Lake Pontchartrain

Interpretation of the basic distributional patterns of the blue crabs within Lake Pontchartrain is complicated by the fact that most samples contained few individuals, and these often exhibited a wide range of sizes. Statistical characteristics have been computed and plotted for each seine or trawl sample containing ten or more specimens obtained during the survey, and the primary conclusions may be simply illustrated by the summer samples plotted in Figure 6. This figure represents the data from all samples containing thirty or more individuals taken during June, July, and August of 1954.

During the summer months small crabs were generally predominant in the seine samples (as indicated by the June sample at station 4-S). Adult crabs were sometimes observed foraging in the shallow areas, but they were greatly outnumbered by the hordes of young blue crabs found in the shallow, fresher, marginal waters of the lake throughout the summer months. During the winter the young seemed largely to forsake the shallow feeding grounds for refuge in deeper water.

Summer trawl samples, on the other hand, contained medium-sized and adult crabs but few of the very small individuals. Adult crabs frequently predominated in these trawl samples. Allowing for differences in mesh size and operational technique, the general size differences observed between the seine and trawl samples appear to be real.

Station number five, which represents several deep dredge holes near the south shore, is not strictly comparable with the other stations. It appears that small crabs are differentially attracted or held by these holes since nearly every month the samples from this station contained a relatively greater percentage of young than did trawl hauls from other stations.

Ignoring samples from the seine station and from trawl station number five, it is clear that during the summer months crabs from the most saline waters averaged larger in size than those from the fresher areas. This is especially apparent in the more complete August collections. Suttkus (1954) found a negative correlation between salinity and body size in samples of young croakers from Lake Pontchartrain, and the positive correlation observed in the case of the blue crabs reflects in large measure the tendency of the adult females to forsake fresher areas following copulation. This tendency may best be expressed by comparing the sex ratios of adult crabs in samples taken from the Rigolets (Station No. 1) with those from Pass Manchac (Station No. 8). The July and August samples from the Rigolets contained 41 and 38 adults with 70.3 and 76.3 percent females, respectively. The July and August samples from Pass Manchac contained 33 and 12 adults with 15.2 and 0.0 percent females, respectively. In Lake Pontchartrain trawl samples taken during the summer some distance from the shoreline, adult males were almost invariably present in great excess of the number of adult females. In summer trawl samples taken near shore, however, the females often were the most abundant adult group. This pattern of distribution of the adult females might suggest that in their pre-spawning migrations these females navigate by following the shoreline.

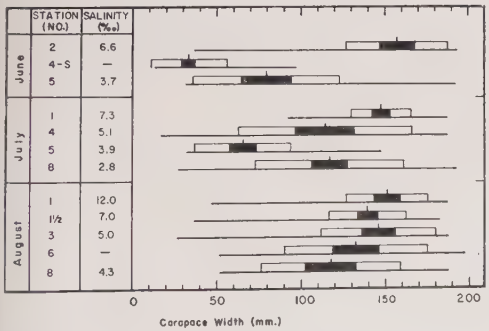

FIGURE 6.—Sample characteristics of all collections containing thirty or more individuals obtained during the months of June, July, and August of 1954. For each sample the station number (as indicated in Fig. 1) and salinity are given, as well as the following sample characteristics: size range (heavy horizontal line), mean (short vertical line), plus and minus two standard errors of the mean (black rectangles), and plus and minus one standard deviation (black rectangles plus white rectangles). For discussion of this procedure see Hubbs and Hubbs (1953).

Food habits

Food habits of the blue crab have recently been summarized by Van Engel (1958) and by Darnell (1958). The zoea larvae have been found to consume a number of microscopic forms but to grow successfully only when fed yellow dinoflagellates. The megalops is omnivorous. Postlarval crabs consume a great variety of plant and animal materials, both living and dead. These include bottom debris, small crabs (including their own kind), clams, mussels, snails, aquatic insects, barnacles, fish-flesh, algae, seaweeds, and marsh grass. Food habits seem to vary from one place to another, probably in relation to availability, but within a given area the young and the adult may feed upon essentially the same types of materials. The blue crab is definitely cannibalistic. Darnell (*loc. cit.*) concluded that in Lake Pontchartrain the species must be considered a detritivore, bottom predator, and general scavanger.

Parasites

In the Lake Pontchartrain survey no special effort was made to study parasites, but when rhizocephalans were observed they were recorded. During the project a total of nine blue crabs were found to be parasitized by the rhizocephalan *Loxothylacus texanus* Boschma. Only three of these specimens were obtained from Lake Pontchartrain, and the remaining six were taken from Lake Borgne and Chandeleur Sound. The data suggest that the incidence of infection was far higher in the more saline waters, which corroborates a similar finding of Gunter (1950) in Texas. A single specimen from Lake Borgne was doubly infected. Curiously, four parasitized individuals were obtained in a single collection from Petit Pass in Lake Borgne in August. Reinhard (1950) has discussed the effect of this parasite in destruction of the gonads and general feminization of the host. No information was obtained regarding nemertean or octolasmid parasites. During the summer months very large crabs were occasionally encountered in Lake Pontchartrain with carapaces heavily "fouled" with barnacles, hydroids, and other sessile organisms. Such crabs may represent post-spawn females returning from Lake Borgne, but there is no proof of this.

Activity cycles

Fingerman (1955 a, b) studied chromatophore activity in blue crabs from Lake Pontchartrain and demonstrated rhythms of dispersal which he correlated with known diurnal, tidal, and lunar cycles. The ecological significance of such physiological rhythms is still unknown. Hedgpeth (1950) stated that most of the blue crab population inhabiting the salt flats of southern Texas seems to be made up of small individuals which come in with the tides. Darnell (1958) suggested that diurnal feeding rhythms may characterize the Lake Pontchartrain population with juveniles and adults feeding largely at different periods of the twenty-four hour cycle. Lambou (1952) mentioned that the young are especially abundant on the shallow flats at night.

During the Lake Pontchartrain survey a series of four twenty-four hour studies was carried out at a fixed station (Station No. 3) to determine diel periodicity in sampling availability of the various species. Larval crabs, especially megalops, were noted to be especially abundant under night lights in August. Fifteen minute trawl hauls were made at 2-hour intervals. These revealed no significant periodicity in the August study, but the 24-hour studies of November, February, and May are quite suggestive. In the November study the peak capture was obtained in the 6:00 p.m. sample, in February it was obtained at 6:00 a.m., and in May the peak occurred at about 3:00 a.m. The clearest indication of a significant 24-hour capture pattern occurred in the February period. In this study only three crabs were taken in the 8:00 a.m haul, the frequency increased gradually during the day, then rose sharply during the night collections to a maximum of 55 crabs in the 6:00 a.m. haul. The significance of such capture patterns in terms of species behavior is not immediately clear, but the data are somewhat reminiscent of those obtained by several workers on the pink shrimp (*P. duorarum*) where periodicity in capture may be correlated with periodicity in movement (Burkenroad, 1949). Further study of natural invertebrate activity cycles promises to be quite rewarding.

DISCUSSION

The life history of the blue crab in southeastern Louisiana has not been definitely established in the present study. The following points, however, appear consistent with the data obtained from the Lake Pontchartrain survey as interpreted in light of the published information regarding the life history of the species in Chesapeake Bay and in southern Texas.

Present evidence suggests that in Louisiana, as elsewhere, mating occurs in the relatively fresh areas during the warmer months. This is followed by migration of the mated females back to the more saline waters of Lake Borgne and Chandeleur Sound, where spawning and larval development take place. Young crabs migrate from these outside waters to the inside fresher areas such as Lake Pontchartrain. Here the smallest crabs tend to seek out the freshest and shallowest marginal areas for feeding and growth. Maturation takes place in these inside waters. The same general pattern has been pointed out by Hay (1905), Churchill (1919), and others for Chesapeake Bay and by Gunter (1950) and Daugherty (1952) for Texas. Lambou (1952) has indicated the extreme abundance of young crabs in the shallow fresher waters adjacent to Lake Pontchar-

train, and Gunter (1938) has recorded the presence of the blue crab in fresh waters of Louisiana many miles from the Gulf.

Whereas hatching and most larval development seem to occur outside the lake, young crabs appear in abundance in Lake Pontchartrain in May, one or two months earlier than in Chesapeake Bay. Some apparent blue crab larvae are taken throughout the summer, and a secondary peak of spawning may occur in the fall. There is no evidence of winter spawning either in Louisiana or in Chesapeake Bay. By contrast, Daugherty (*loc. cit.*) stated that in the populations of southern Texas spawning may continue throughout the year if the winter is sufficiently mild. He noted, however, that in the Texas area intensive spawning takes place only from March to September with two peaks of intensity, one in March-April and a second in June-July, either of which may represent a maximum.

No accurate estimate may yet be made regarding the duration of larval life of the Louisiana crabs, although Costlow, Rees, and Bookhout (1959) determined that 37 to 44 days are required in laboratory-reared specimens from Chesapeake Bay. The present limited data suggest that spring-spawned young may attain a size of 65 mm. by September of the first year. In contrast to the Chesapeake Bay population where growth ceases during the colder months, the present data do not rule out the possibility of limited winter growth of the Louisiana young. The effect of such winter growth in shortening the period of adolescence is not known. The present information suggests that about the same length of time is required to reach maturity in the Louisiana population as in the Chesapeake Bay population, i.e. from eight to twelve growing months. Repeated spawning by adult females has not been established for the Louisiana population, and the fate of post-reproductive females is unknown.

The virtual disappearance of adult crabs, particularly the adult females, from the winter samples may be due to migration or hibernation or to both. Some of the local fishermen maintain that they have located winter hibernation grounds, and large winter catches of adult blue crabs during past years (before this became illegal) tend to substantiate their statements.

ACKNOWLEDGMENTS

The author is indebted to R. D. Suttkus for aid during the field work, to F. A. Chace for identification of the several species of Lake Pontchartrain crabs, and to R. E. Reinhard for identification of the rhizocephalan parasite. W. A. Van Engel and F. Wojcik kindly read the manuscript and offered valuable suggestions. Sincere appreciation is expressed to the author's wife, Jeanne H. Darnell, for aid in all aspects of the present work and especially for providing plankton data upon which the larval distribution study is based. Further thanks are extended to the Commercial Seafoods Division of the Louisiana Wildlife and Fisheries Commission for financial support of the field work and to the Marquette University Graduate Committee on Research for financial assistance during the analysis of the data.

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Effects of Certain Chemicals on Mucus-Producing Cells of Petromyzon marinus

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ABSTRACT

Tissue samples that contained slime-secreting cells were taken from the gills and epidermis of larval lampreys that had been poisoned by several compounds. Histochemical treatment of these pathological tissues helped delineate the fate of these mucus-producing areas of the ammocetes. It was shown that the slime-secreting cells, located at the tips of the gill filaments, lining the gill chamber, and scattered throughout the epidermis reacted differently to the same toxicant. The secretory cells of the gills were, without exception, the most sensitive to chemical attack.

INTRODUCTION

Early work done by Carpenter (1927, 1930), Ellis (1937), and Westfall (1945) proved that the slime-secreting cells of the gills and epidermis of some bony fishes are the first line of defense against certain external irritations. While investigating the possibility of selective chemical control for larval sea lampreys, *Petromyzon marinus,* under the direction of the U. S. Fish and Wildlife Service, the effects of many substances on various parts of their bodies were observed. Some toxicants stimulated excessive slime secretion. To help explain this response more clearly, selectively stained sections through the gills and epidermis of these pathological specimens were prepared for microscopic examination.

MATERIALS AND METHODS

Tissue samples containing slime-secreting cells were subjected to a histochemical technique that showed the presence of free or bound mucopolysaccharides. The procedure is commonly called the PAS method. It was described in Lillie (1948) and discussed by Pearse (1954). The poisoned tissues were fixed in 10 percent formalin, imbedded in paraffin, and cut into 10-micra sections. The sections were then mounted on slides, deparaffinized, incubated one hour in saliva at 37° C, oxidized in periodic acid, stained in Schiff's reagent, washed and covered. Tissues were examined from the gills and epidermis.

NORMAL AND PATHOLOGICAL HISTOLOGY

The tissues of a normal larva were prepared in the manner described. In the normal tissue, the tips of the gill filaments stained deeply wherever the precursor of slime was to be found (Fig. 1). These dark-staining areas do not occur over the entire gill filament, but occur just at its tip (Bevelander (1935), described abundant mucus cells in the interlamellar space and occasional ones on the lamellae). These scattered mucus cells either were lacking or did not respond to staining by the PAS technique in any of my preparations. Mucus-secreting cells may be seen also in the walls of the gill chamber above the gill filaments (Fig. 2). These cells all appear turgid with their full complement of secretory substances. The epidermis of the same specimen appears at the upper left of Figure 2. Its outer edge shows the dark-staining, smooth surface which is characteristic of normal activity of the secreting cells in this tissue.

The sodium salt of N-4-nitrophenyl-4-chlorobenzene sulfonamide, a compound toxic to ammocetes at a concentration of less than 1 p.p.m., had a severe effect on their gills and epidermis. In some larvae the cells that formed the supporting framework for the gill capillaries were destroyed. Most of the slime-secreting cells at the tips of the gills and in the walls of the gill chamber were cytolized. The resulting structure was much reduced in efficiency, if functional at all (Fig. 3).

The epidermis appeared intact but excessive secretory activity could be observed (Figs. 4 and 5). This tissue seemed to respond to the

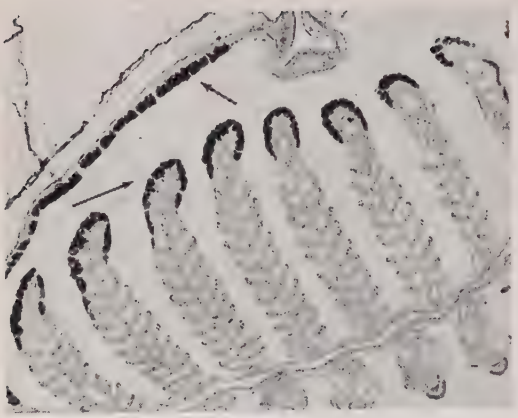

FIGURE 1.—Gills and lining of gill chamber possessed by a normal lamprey. Black-staining cells of slime-secreting areas are indicated by arrows. 60 millimeter larva. 100 X.

FIGURE 2.—Same specimen shown in Figure 1, illustrating normal epithelium. Its outer edge is typically a dark-staining smooth surface. No secretory activity is apparent.

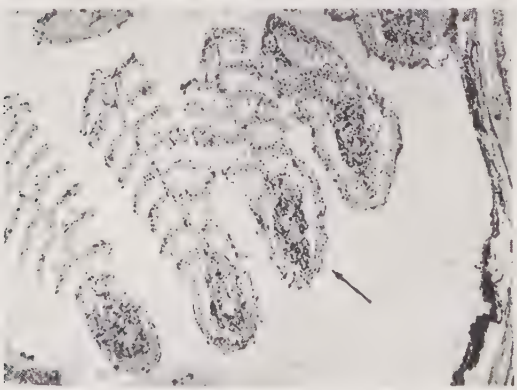

FIGURE 3.—No stain reaction is visible in remains of mucus cells at tips of gills. Larva exposed to N-4-nitrophenyl-4-chlorobenzene sulfonamide. 160 millimeter larva. 150 X.

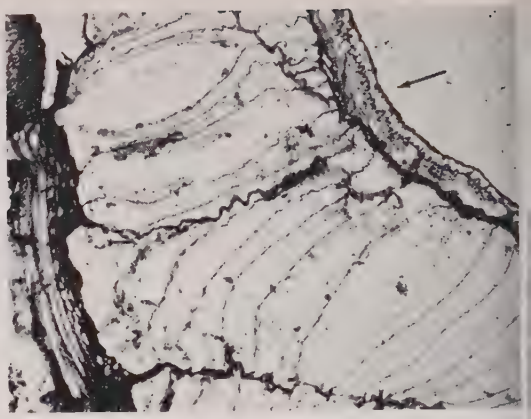

FIGURE 4.—Increased secretory activity in the epidermis of larva treated with N-4-nitrophenyl-4-chlorobenzene sulfonamide. 160 millimeter larva. 100 X.

FIGURE 5.—An enlarged segment of the epidermis shown at upper right of Figure 4. Shows globules of mucus gathered at the surface. Epidermis is between the arrows. 160 millimeter larva. 660 X.

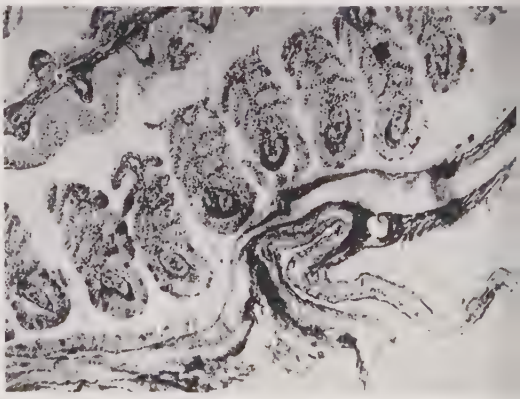

FIGURE 6.—Abnormal condition of gills resulting from immersion in benzylphenyl dimethyl ammonium, 2,4-dinitro-6-methyl phenoxide is shown. 180 millimeter larva. 100 X.

chemical stimulation by producing waves of slime. While one layer was being liberated at the surface, the next was forming within the secretory cells. At time of death, the sensitive gills had lost their auto-protection, and entrance of the toxicant could have taken place in that area.

Another toxicant lethal to ammocetes at concentrations of approximately 1 p.p.m. was benzylphenyl dimethyl ammonium 2, 4-dinitro-6-methylphenoxide. Microscopic examination of gills and epidermis of specimens treated with this substance did not show extensive change. The mucus cells at the tips of the gill filaments stained a much lighter color than those of a normal animal. This difference was interpreted to mean that the reserve supply of the percursor of slime had been mostly used. A few of the terminal secretory cells contained small spots of dark-staining material, but the accumulations were much below normal (Figs. 6 and 7). The cells themselves appeared unchanged in size and shape.

The cuboidal cells lining the gill chamber reacted similarly. Their shape and size appeared to be normal, but they were devoid of the dark-staining substances usually present (Fig. 6).

The epidermal cells were just beginning to show secretory activity at the time of death of the larva. They were not elongated, and the cuticle was intact. Epidermal reaction to this toxicant was not vigorous, but the beginning of excessive slime production can be seen as dark-staining areas beneath the cuticle (Fig 8).

An investigation of the effects of the fungicide, zinc dimethyldithiocarbamate gave interesting results. Lamprey larvae subjected to a concentration of 0.5 p.p.m. died in 6 hours. Sections showed that the gill filaments were completely destroyed as functional units (Fig. 9). The shape of the secreting cells of the skin was so irregular that the epidermal layer appeared much thicker than in a normal specimen. The many dark-stained, papilla-like structures protruding from the surface cells are interpreted to be mucin collected at the tips. These nipple-like structures break off, forming part of the secretion along with the mucus. Undoubtedly, the cells were under very strong stimulation. Secretion by the pathological specimens of much of the mucopolysaccharide that stained in normal lamprey epithelium caused the over all staining of the tissue to be less intense. The compact arrangement of the normal tissue had been greatly disrupted (Fig. 10).

Calcium hydroxide, another slime-stimulating compound, produced death in 11 hours when larvae were subjected to a concentration of 50 p.p.m. Macroscopic examination showed a thin film of coagulated slime over the entire ammocete. The opacity of this coating caused the ammocetes to have a milky appearance externally. The presence of some Schiff-positive material in cells bordering the inside edge of the gill chamber (stained sections) indicated they were possibly still capable of secreting slime. The large mucus-producing cells at the tips of the gill filaments were normal in shape, but they stained only a light pink. This weak staining indicated that their supply of the precursor of slime was exhausted, and they were no longer able to produce a protective layer to surround the gill filaments. The gills themselves did not exhibit damage (Figs. 11 and 12). The epidermis was intact, but showed secretory activity (Fig. 13).

SIGNIFICANCE OF HISTOLOGICAL CHANGES

In each larval lamprey sectioned, the mucus-producing ability of the secretory cells of the gills was most strongly affected. The effects of the toxicants ranged from simple exhaustion of their slime supply without apparent harm to the cells, to complete destruction of the gills. These delicate structures may be completely destroyed and death of the organism may occur before the epidermal defenses are penetrated. The cuboidal lining of the respiratory chambers gave an intermediate reaction, but one more like the gill cells than the epidermal cells. Its supply of the precursor of slime generally lasted longer than did that of the secretory cells at the tip of the gill filaments, but this tissue was not as resistant as the outer body covering.

The exterior of the ammocetes, including the brush border, stained positively throughout. Beneath this thin line of dark-staining material on the surface, the Schiff-positive mucopolysaccharide appeared to be in layers. The individual slime-secreting cells did not stain completely. The purple color was concentrated at the ends of the cells toward the exterior. The "goblet" cells found in the skin were Schiff-negative.

The fact that the epidermal mucus-producing cells stained partially, whereas those of the gill stained completely, indicated that these two types of epithelial cells may be functionally different.

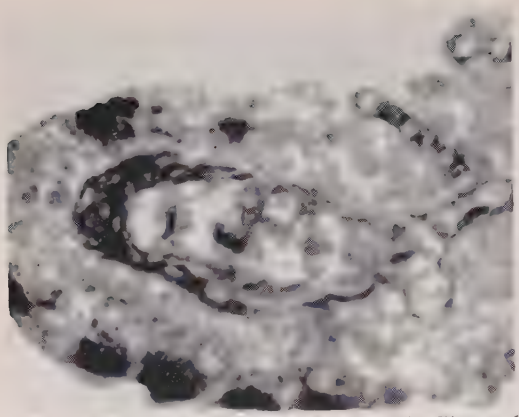

FIGURE 7.—One gill tip of specimen in Figure 6 reproduced to show remnants of normal mucus supply (black-stained areas). Compare with Figure 1. 180 millimeter larva. 660 X.

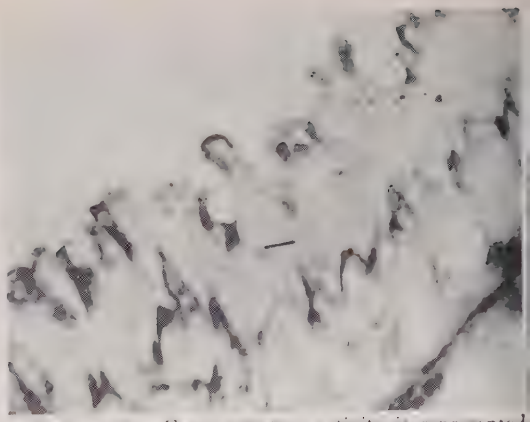

FIGURE 10.—Great secretory activity is represented by the irregularity of the epidermal surface, but slime was still being produced. Larva treated with zinc dimethyl dithiocarbamate. 75 millimeter larva. 660 X.

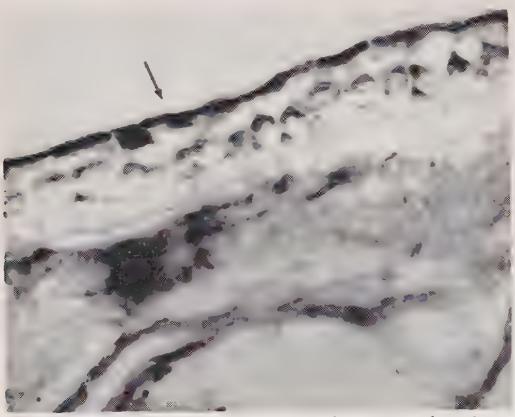

FIGURE 8.—Smooth surface of the epidermis at upper part of illustration is unbroken, but deeper layers of cells show secretory activity. Larva treated with benzylphenyl dimethyl ammonium 2,4-dinitro-6-methyl phenoxide. 180 millimeter larva. 100 X.

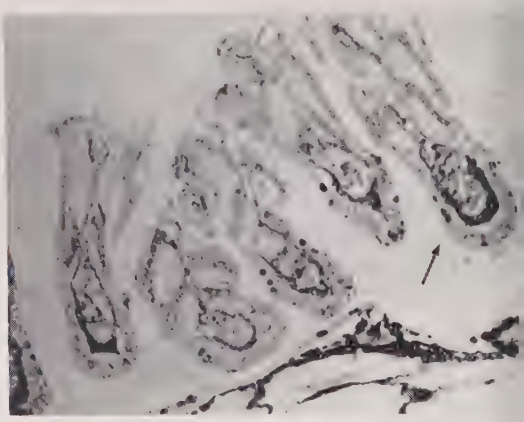

FIGURE 11.—Scattered black spots around gill tip indicate some slime secretion yet possible, but most of cells had exhausted their supply. Larva treated with calcium hydroxide. 100 millimeter larva. 100 X.

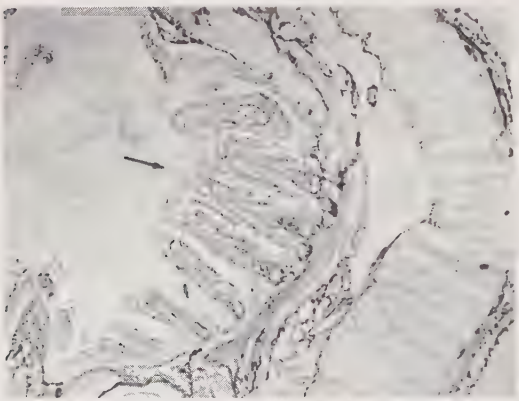

FIGURE 9.—Left part of illustration shows all that remained of the gill structure. The cells that lined gill chamber were destroyed also. Larva treated with zinc dimethyl dithiocarbamate. 75 millimeter larva. 100 X.

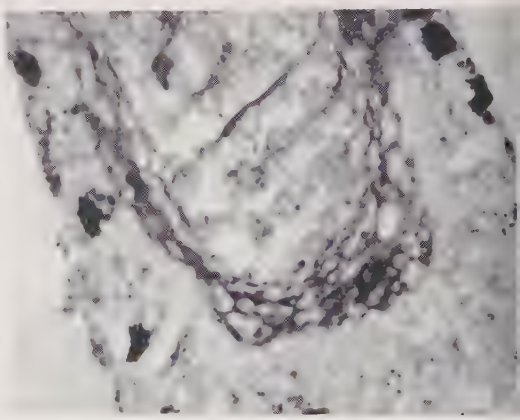

FIGURE 12.—A gill tip of specimen in Figure 11 enlarged. Shows the small black patches of slime-producing substances that were left after exposure to calcium hydroxide. 100 millimeter larva. 660 X.

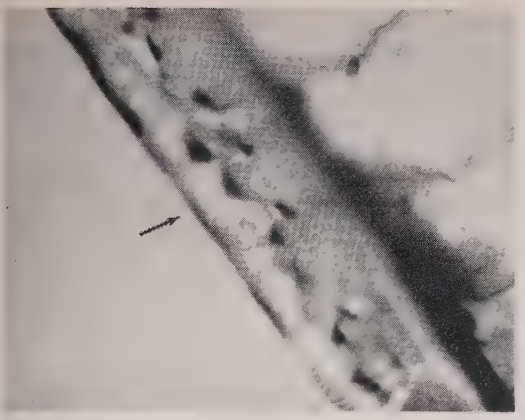

FIGURE 13.—Little abnormal activity is demonstrated by the epidermis of this larva treated with calcium hydroxide. 100 millimeter larva. 100 X.

These very few experiments do not permit definite conclusions, but it seems probable that substances used in these assays which caused excessive slime secretion brought about the death of the lamprey larvae either by entering the body through the delicate gills or by completely destroying these important structures. The relatively protected secretory cells of the epidermis continue to coat the exterior of the animal, making this surface much more difficult to penetrate.

ACKNOWLEDGMENTS

Dr. Karl F. Lagler, University of Michigan, was the major advisor in this work. Dr. James W. Moffett, Chief, Great Lakes Fishery Investigations, U. S. Fish and Wildlife Service, also gave advice in the work personally, and made available financial aid and equipment. Dr. George M. Moore, University of New Hampshire, provided necessary space and equipment vital to completion. Allan W. Handy, M. D., pathologist for the cities of Rochester and Dover, N. H., prepared slides and helped interpret certain pathological manifestations.

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Growth of Marked Silver Salmon (Oncorhynchus kisutch) of the 1950 Brood in Puget Sound[1]

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ABSTRACT

Silver salmon (*Oncorhynchus kisutch*) of two different stocks were marked by excision of fins and released during the spring of 1952 into Minter Creek and Lake Washington drainages of Puget Sound, Washington. Over 800 of the marked salmon were recovered during 1952 and 1953 from the sport and commercial fisheries of Puget Sound, the Pacific Ocean, and closely adjoining waters. Mature adults returning to spawn were recovered at traps and weirs at the hatcheries where they were originally released. The growth over the entire 3-year life cycle of the salmon released into the Lake Washington drainage when plotted graphically showed variation in length at maturity from less than 40 to over 80 centimeters in fork length. Salmon from the Lake Washington drainage taken in salt water at the same time and place were larger than salmon from Minter Creek. The average relative lengths of salmon from Minter Creek and Lake Washington recovered in the Pacific Ocean were the same as recorded for the mature salmon recovered at the hatcheries. Salmon migrating to different areas in salt water attained different average lengths at maturity. The average lengths of marked salmon recovered from the Pacific Ocean were always larger than fish recovered at the same time from Puget Sound, and salmon of intermediate size were taken in the Strait of Juan de Fuca and in the Pacific Ocean immediately adjacent. Difference in average size between the Lake Washington salmon (Green River, Soos Creek, stock) and Minter Creek salmon is considered to be a racial characteristic. Exact reasons for differences in length attained by the salmon taken from different areas are not known.

INTRODUCTION

The length at maturity of silver salmon (*Oncorhynchus kisutch*) may be influenced by genetic factors through varying degrees of reproductive isolation of the populations on the spawning grounds, and by environmental factors through differences in available food and feeding habits of populations migrating to different areas in the ocean. Pressey (1953) examined lengths of unmarked silver salmon taken by sport fishermen in Puget Sound, Washington and suggested that there was a population of silver salmon feeding within Puget Sound which was of smaller size at maturity than silver salmon feeding in the Pacific Ocean. Milne (1950) and Prakash and Milne (1950) showed that unmarked silver salmon taken in the commercial troll fishery off the west coast of Vancouver Island, British Columbia were longer than those taken in the troll fishery in the Strait of Georgia (Figure 1), and indicated that these areas contained populations of feeding silver salmon which did not intermingle until the spawning migration. No studies of the effects of heredity and environment on the length at maturity of silver salmon which have involved marked fish have been reported in the literature. In the spring of 1952 five groups of silver salmon marked by the excision of fins were released into two

FIGURE 1.—Locations of planting and recovery of Silver Salmon referred to in text.

[1]University of Washington, College of Fisheries, Contribution No. 63.

drainages entering Puget Sound. This paper presents the growth of these salmon in Puget Sound, Strait of Juan de Fuca, and the Pacific Ocean as indicated by the length of marked fish recovered from fisheries in these areas, and by the length of marked fish recovered in traps and weirs at the hatcheries where the salmon were originally released.

DESCRIPTION OF GROUPS OF MARKED SALMON

On January 19, 1952, silver salmon fingerlings were taken from hatchery ponds at the Green River (Soos Creek) hatchery operated by the State of Washington Department of Fisheries and transported to the University of Washington and to the Issaquah hatchery located on the Lake Washington drainage (Figure 1). The salmon were marked by faculty and students of the College of Fisheries and were released March 18-19, 1952 (Donaldson and Allen, 1958). Salmon marked by clipping the left ventral fin (LV) were released into Lake Washington at the University of Washington, College of Fisheries hatchery; salmon marked by clipping the right ventral fin (RV) were released into Issaquah Creek of the Lake Washington drainage at the State of Washington Department of Fisheries hatchery at Issaquah. At the time of planting, the LV group had a greater average length than the RV group (Figure 2). This difference in length resulted from differences in water temperature and diet at the two hatcheries during the 3-month period from January 19 to March 18-19, 1952.

On March 3, 1952, three groups of salmon were selected from the same ponds and marked at the Minter Creek hatchery (Salo and Bayliff, 1958). On March 3, 1952, two groups of fish were planted into Minter Creek; one group was marked by clipping the adipose and anal fins (Ad-An), and the other by clipping the anal and right ventral fins (An-RV). The third group of salmon was marked by clipping the dorsal and right ventral fins (D-RV), and was held until May 5, 1952, before planting.

Great effort was made to have the Ad-An and An-RV groups of the same length by selecting and marking these two groups first (E. O. Salo, 1959. Personal Communication). The D-RV group was marked last and the salmon then available were larger than the salmon given the Ad-An and An-RV marks (Figure 2).

The D-RV group was reared for 14-months before planting. All other groups were reared approximately 12 months before planting. The Ad-An group was "scatter-planted" (liberated at several points). All other groups were "mass-planted" (liberated at a single point).

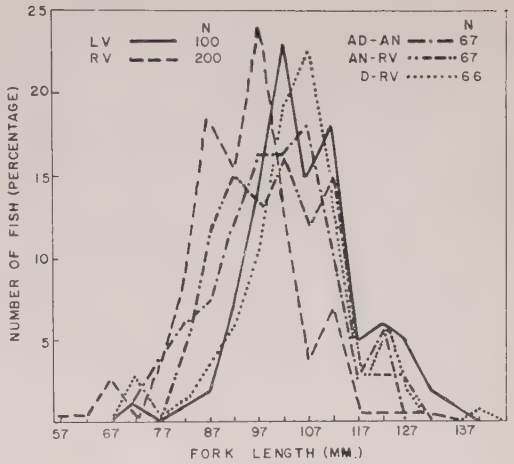

FIGURE 2.—Length-frequency of five groups of 1950 brood silver salmon at time of marking.

COLLECTION OF DATA

After liberation into Minter Creek and Lake Washington drainages, the five groups of salmon migrated into Puget Sound and to the Pacific Ocean. Different percentages of salmon in each group remained within Puget Sound and closely adjoining waters or migrated to the Pacific Ocean (Allen, 1956). In 1952 and 1953, fisheries agencies of the Pacific Coast conducted a rather intensive program of sampling the catch of all silver salmon fisheries to recover marked fish (Pacific Marine Fisheries Commission, 1953). Data available for marked silver salmon recovered by biologists of the States of Oregon and Washington and the Province of British Columbia in sampling of the landings of the commercial troll fisheries were: fork length to the nearest half centimeter, date of landing, and area of catch. For marked fish recovered by the Washington State Department of Fisheries in sampling the catch of sport fisheries within Puget Sound, the data available were fork length in centimeters, date of catch, and area of catch. Information on marked salmon taken in the sport fisheries was also obtained from return of self-addressed post cards distributed by the Washington State Department of Fisheries to sportsmen, sport tackle dealers, and boat rental operators. On these cards information was recorded as to

"overall" length, location and date of catch. Marked fish taken in Puget Sound, Strait of Juan de Fuca, and in the Cape Flattery area were reported by post card.

Salmon escaping the fisheries in salt water returned to the Minter Creek and Lake Washington drainages during the fall of 1953 and winter of 1954. Marked salmon from the five groups were recovered at hatchery traps and weirs located at Minter Creek, University of Washington, and Issaquah hatcheries (Donaldson and Allen, 1958; Salo and Bayliff, 1958). The author determined the fork length in centimeters of all the LV group returning to the University of Washington traps. Biologists at the Issaquah hatchery obtained the fork length to the nearest half-inch of salmon of the RV group returning to the weir at the Issaquah hatchery. Allen (1956) estimated that about 75 percent of the RV group entering the Issaquah drainage were captured at the Issaquah hatchery. All salmon returning to the Minter Creek weir were examined daily by hatchery personnel for marks[2]. On certain days, picked at random, all marked salmon were measured for fork length in centimeters. About nine percent of the marked salmon of the Ad-An, An-RV, and D-RV groups recovered at the Minter Creek station were measured for length.

All data on lengths of marked fish are reported as fork length in centimeters. The lengths of fish reported on post cards were converted to fork length by means of a conversion equation of Van Hyning (1951).

Approximately 380 Lake Washington salmon (LV, RV marks), and 425 Minter Creek salmon (Ad-An, An-RV, D-RV) were actually reported from the catch of sport and commercial fisheries. Complete information on length of fish, area of recovery, or time of recovery was not available for all the marked salmon reported.

SOURCE OF ERROR

Silver salmon of the 1950-brood year bearing LV and RV marks, which duplicated those planted into Puget Sound, were released into the Columbia River from the Little White Salmon fish-cultural station operated by the United States Fish and Wildlife Service (Figure 1)[3]. The marked salmon released at

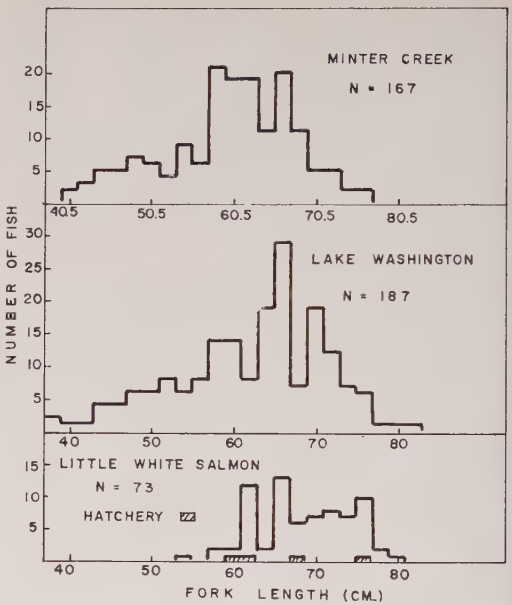

FIGURE 3.—Length of marked 1950 brood silver salmon recovered during the fall of 1953 and winter of 1954 at Minter Creek hatchery (Ad-An, An-RV, and D-RV groups combined), at the University of Washington and Issaquah Hatcheries (LV and RV groups combined), and from the Columbia River gill-net fishery and Little White Salmon hatchery.

the Little White Salmon hatchery, where no natural run of silver salmon occurred, were from the Quilcene fish-cultural station (Hood Canal, Washington). In 1951 and 1953 marked silver salmon yearlings were released into the Columbia River drainage at the Lewis and Toutle River hatcheries by the State of Washington Department of Fisheries (Figure 1). Analysis of the recovery of these marks in the commercial troll fisheries by the Washington State Department of Fisheries showed these salmon migrated predominately southward from the mouth of the Columbia River (Allen, 1956). Based upon the behavior of the silver salmon released in the Lewis and Toutle rivers, it was assumed that the majority of the marked salmon released in 1952 at the Little White Salmon hatchery also migrated southwards into the Oregon and California fisheries. However, there is no doubt that some of the LV- and RV- marked salmon recovered in the Washington troll fishery were from the

[2]Salo, E. O. and R. E. Noble, 1954. Wash. State Dept. Fish., Minter Creek Biol. Stat., Prog. Rept., Nov., 1953- Jan., 1954. Unpublished.

[3]Total numbers released — Little White Salmon, 29,652; Lake Washington, 71,238.

Little White Salmon releases, especially from GraysHarbor (Area VIII), Figure 1). About ten percent of the recoveries in the Washington troll fishery were estimated to have originated from the salmon released at the Little White Salmon station (Allen, 1956).

The marked salmon returning to the Little White Salmon hatchery captured in the Columbia River gill-net fishery were larger than the marked fish recovered in the escapement to Lake Washington hatcheries (Figure 3). This difference might have been due to the selective actions of the Columbia River gear. Petersen (1954) showed selection of larger fish by Fraser River gill nets, however, the Columbia River fishery employs gill nets of two different types—a "trammel" net, and the "apron" net, which is a gill-net faced with a second web (apron) of much larger mesh. The apron very likely selects more big fish and the trammel net more small fish than the Fraser River gill nets. As the amounts of these two kinds of gear used to catch the salmon in the gill-net fishery was not determined, it cannot be stated that the salmon returning to the Little White Salmon hatchery actually were larger than the Lake Washington salmon.

GROWTH IN LENGTH OF SALMON FROM LAKE WASHINGTON

Salmon which had been released into the Lake Washington drainage in March, 1952 were entering the Puget Sound sport fishery by July, 1952. Legal size limit in the sport fishery in Puget Sound was 30.5 centimeters, or 12 inches. In July and August, sampling by the Washington State Department of Fisheries of silver salmon at Bush Point (Figure 1) with a commercial-type reef net recovered 10 marked Lake Washington salmon. The lengths of these fish were not recorded; however, comparable data were obtained in the summer of 1955 from the progeny of the LV group of

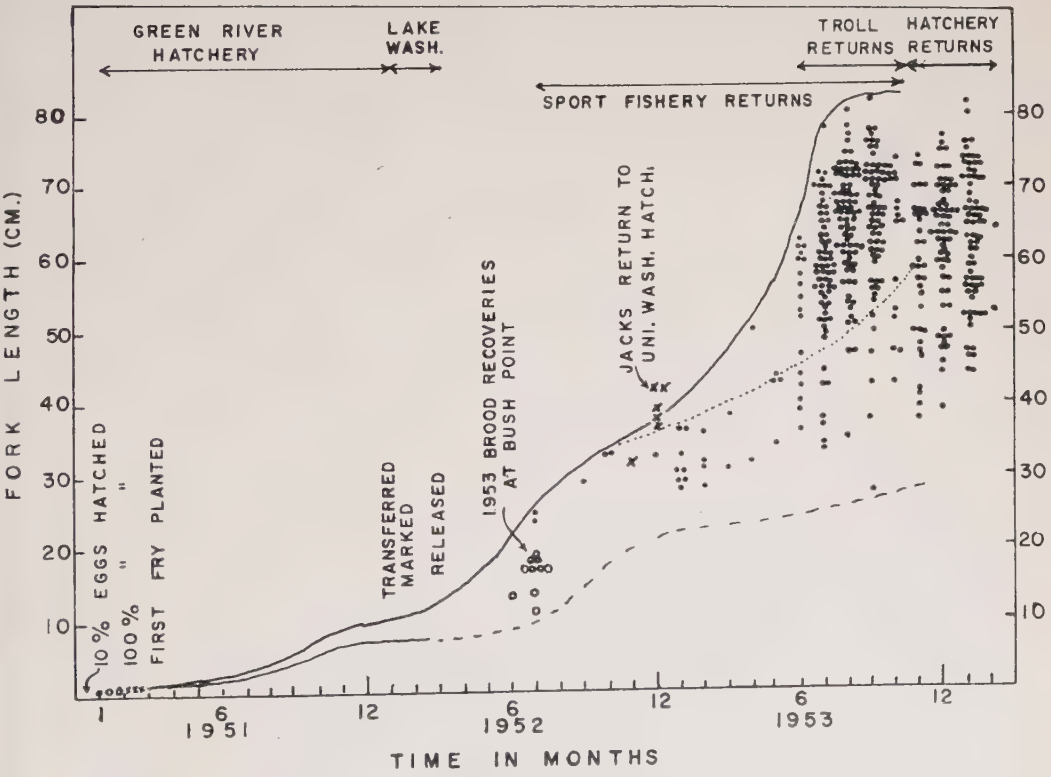

FIGURE 4.—Growth in length by month of marked 1950 brood silver salmon from Lake Washington (LV and RV groups combined). Maximum rate of growth by individuals within the population indicated by the solid line, and estimated minimum rate of growth by broken line. Dotted line separates returns from within Puget Sound and closely adjoining regions (below) from those of the Pacific Ocean (above).

salmon which were recovered at Bush Point as members of the 1953-brood year. The LV group was bred selectively at the College of Fisheries and the resulting salmon marked before release (Allen 1958a).

Commercial troll recoveries in the Pacific Ocean began in late June of 1953. Legal size limit in this fishery was 56 centimeters, or 22 inches. All available data on the lengths of Lake Washington salmon from these sources were assembled to estimate the growth in length of the Lake Washington salmon during their entire life cycle (Figure 4). Individual variation in length at a particular age was much more extensive than shown by Shapovalov and Taft (1953) for silver salmon in Waddell Creek, California. These authors had no ocean recoveries on which to estimate the monthly growth in length by Waddell Creek salmon during their salt-water existence. In the present study, "jack" silver salmon (male silver salmon maturing as two-year-olds rather than as three-year-olds) that returned to the College of Fisheries were larger than fish of the same age recovered from the fisheries (Figure 4). This is also at variance with Shapovalov and Taft who showed jacks to be smaller than other individuals of the same age in their population.

COMPARISON OF GROWTH IN LENGTH BETWEEN SALMON FROM MINTER CREEK AND LAKE WASHINGTON

Lengths of all marked salmon recovered in the Pacific Ocean from all sources (Oregon, Washington, British Columbia) are presented by two-week intervals in Table 1. During every period Lake Washington salmon were larger, on the average, than Minter Creek salmon. The Lake Washington salmon recovered in the escapement were also larger than Minter Creek salmon recovered in the escapement (Figure 3). Of the marked salmon from the three Minter Creek groups recovered in the Pacific Ocean, the Ad-An were of largest average size, and the D-RV the smallest (Table 1). The relative lengths of salmon in these three Minter Creek groups recovered in the Pacific Ocean were also the same as for those fish recovered in the escapement to the Minter Creek hatchery (Figure 5).

It was noted previously that salmon living in Puget Sound and closely adjoining waters apparently reached a smaller average size at maturity than fish migrating to the Pacific Ocean (Milne, 1950, and Pressey, 1953). Allen (1956) showed that very few marked salmon of the 1950 brood from Minter Creek and Lake Washington recovered in Puget Sound exceeded 58 centimeters in length, whereas very few fish taken in late summer from the Pacific Ocean were less than 58 centimeters[4]. Therefore in comparing the relative length of Minter Creek and Lake Washington salmon in the escapements with the fish recovered in the Pacific Ocean (Figures 3 and 5), only those salmon greater than 58 centimeters have been considered.

The D-RV group of the Minter Creek salmon were later, on the average, than the other four groups in leaving Puget Sound, and were later, on the average, in migrating back to Puget Sound and to Minter Creek (Allen, 1956). Salo and Bayliff (1958) showed that the D-RV group had the lowest rate of survival from egg to returning adult of the three Minter

[4]See discussion under "Variation in Size of Salmon with Area of Recovery" and Table 2.

TABLE 1.—*Average fork length (centimeters) of marked 1950-brood silver salmon recovered in the Pacific Ocean troll fisheries in 1953 by time of recovery* [Number of recoveries in parentheses]

Group of marked salmon	Average length during period of recovery						
	June - July 15	July 16-31	August 1-15	August 16-31	September 1-15	September 15-30	Entire Season
LV	57.4 (19)	66.8 (16)	67.3 (19)	64.3 (30)	67.2 (19)	68.1 (16)	65.1 (119)
RV	58.1 (17)	60.6 (15)	65.0 (21)	65.9 (19)	69.1 (17)	69.5 (11)	64.6 (100)
An-RV	60.4 (17)	56.1 (13)	61.3 (13)	60.9 (11)	62.3 (11)	70.1 (1)	60.1 (66)
Ad-An	53.9 (6)	58.1 (4)	61.5 (14)	62.6 (14)	63.2 (7)	64.7 (2)	60.9 (47)
D-RV	60.0 (7)	57.9 (11)	57.3 (7)	60.2 (7)	60.0 (3)		58.8 (35)
Lake Washington (LV, RV)	57.8 (36)	63.8 (31)	66.1 (40)	65.0 (49)	68.1 (36)	68.7 (27)	64.8 (219)
Minter Creek (An-RV, Ad-An, D-RV)	59.0 (30)	57.1 (28)	60.5 (34)	61.0 (32)	62.3 (21)	66.3 (3)	60.5 (148)
All groups	58.4 (66)	60.6 (59)	63.5 (74)	63.4 (81)	65.9 (57)	68.5 (30)	62.9 (367)

Creek groups, and noted that, in general, overrearing of silver salmon (such as the 14-month rearing of the D-RV group) resulted in drastically reducing survival. It is impossible to state the exact cause for the smaller average size, peculiar migratory behavior, and reduced survival recorded for the D-RV group. The D-RV group migrated into salt water shortly after planting at the same time as the Ad-An and An-RV groups which had been planted into Minter Creek two months earlier. There is a possibility that before migrating to salt water some minimum period of adjustment after planting to "natural" stream conditions is necessary to attaining a normal physiological and psychological state.

The ocean growth of the Lake Washington salmon (Green River stock) as compared with the Minter Creek stock furnished evidence that the difference in size at maturity between these two stocks may be a racial characteristic. Differences in the average size of the salmon escaping to the hatcheries may be a function of gill net selectivity to which the stocks are subjected.

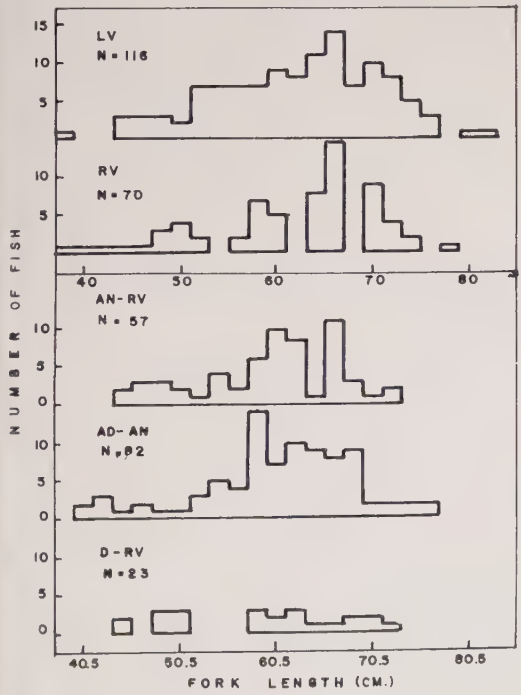

FIGURE 5.—Length of five groups of marked 1950 brood silver salmon recovered at the University of Washington (LV group), Issaquah (RV group), and Minter Creek (Ad-An, An-RV, D-RV groups).

It is difficult to disregard the fact that Lake Washington salmon taken at the same time, and in the same feeding areas of the Pacific Ocean were, however, consistently larger in average size than the Minter Creek salmon. Prakash and Milne (1958) mentioned that differences in growth might arise from spawning stocks with different feeding habits and growth rates. As indicated above, there were differences in size between stocks in 1953, and that within any one stock differences in feeding area primarily influenced the average length attained at maturity. Which stocks remain within Puget Sound and closely adjoining waters, and to what extent, rather than migrating to the Pacific Ocean, is most probably related to oceanographic conditions present when the downstream migrants enter salt water. Thus the behavior of those remaining within Puget Sound is not considered a racial characteristic *per se*. Similarily, the predominately southward movement from the mouth of Columbia River recorded for marked silver salmon released at the Toutle and Lewis River hatcheries is not considered a racial characteristic.

It was assumed that the oceanographic conditions off the mouth of the Columbia River were comparable from 1951 through 1954 — the period when the present study and the experiments at the Toutle and Lewis River hatcheries were conducted. Recently drastic changes in the oceanography of the north Pacific Ocean have been noticed (California Cooperative Oceanic Fisheries Investigations, 1958, McDonald, 1958). Comparison of behavior and growth of marked salmon planted during the 1949-56 period with that of marked salmon planted after 1956 when the oceanographic changes became evident would be extremely interesting.

VARIATION IN SIZE OF SALMON WITH AREA OF RECOVERY

Data for statistical area "west coast of Vancouver Island" (Area V, Figure 1) used by the Fisheries Research Board of Canada in studying the troll fishery off the west coast of Canada, included landings by those Canadian trollers fishing the 40 Mile Bank, Swiftsure Bank, and the western end of the Strait of Juan de Fuca. These latter areas (II, III, and IV, Figure 1) are used by the Washington State Department of Fisheries. Only a few marked salmon recovered from fishermen landing salmon in British Columbia were taken in

TABLE 2.—*Fork length (centimeters) of Lake Washington salmon (LV and RV groups combined) recovered in the summer of 1953 from eight areas along the west coast of North America*

Area[1]	April-June			August		
	N	Range	Average	N	Range	Average
I Puget Sound	19	32-50	41.9	4	35-59	48.2
II St. Georgia St. Juan De Fuca	5	52-72	57.4	4	56-57	60.2
III Swiftsure Bank Cape Flattery	22	49-70	57.0	7	53.5-65.5	61.3
IV 40-Mile Bank	1		60.5	3	62-69	65.0
V West Coast of Vancouver Island	10	51-70	60.2	15	47-75	63.8
VI Umatilla Reef	20	53-72	63.5	24	57-73	66.6
VII Destruction Is.	4	55-60.5	57.5	18	54.5-81	66.6
VIII Grays Harbor	14	53.5-71	60.7	17	52-78	68.2

[1]See Figure 1 for location of areas.

the southern part of Area V (Figure 1), so any error from this source is considered negligible.

The growth rate of Lake Washington fish remaining within Puget Sound and the Strait of Juan de Fuca differed from those migrating to the Pacific Ocean. This is shown by listing by area the range and mean fork length attained by marked salmon recovered during the summer of 1953 (Table 2). The larger fish were recovered in the Pacific Ocean and the smaller fish within Puget Sound. Furthermore, fish of intermediate size were recovered in the Strait of Georgia-Strait of Juan de Fuca area (Area II), and in the Pacific Ocean immediately to the west of the Straits of Juan de Fuca (Swiftsure Bank-Cape Flattery, Area III).

Further variation in length of salmon with place of capture is shown by the lengths of marked salmon recovered in the commercial troll fisheries from six areas of the Pacific Coast off the west coast of North America (Table 3). No one area consistently produced the largest fish. However, for each group except the D-RV group, salmon of the smallest average size were taken in the Swiftsure-Cape Flattery area. It was possible that the small size of the salmon taken in the Swiftsure-Cape Flattery area was due to a temporal

TABLE 3.—*Average fork length (centimeters) of five groups of marked 1950-brood silver salmon recovered in the Pacific Ocean troll fisheries in 1953 by group by area of recovery* [Number of recoveries in parentheses]

Area of recovery[2]	Average length of group of marked salmon				
	LV	RV	An-RV	Ad-An	D-RV
West Coast Vancouver Is.	64.0 (23)	62.3 (9)	64.0 (3)	59.9 (6)	58.1 (6)
Swiftsure Bank Cape Flattery	61.5 (15)	61.4 (17)	56.1 (6)	58.2 (2)	59.9 (11)
Umatilla Reef La Push	66.1 (34)	62.4 (20)	60.8 (22)	62.2 (13)	63.0 (3)
Destruction Is.	67.8 (11)	65.7 (14)	58.5 (11)	62.1 (12)	51.0 (3)
Grays Harbor	67.6 (21)	66.9 (27)	56.4 (8)	59.3 (8)	58.1 (6)
Oregon Coast[1]	—	—	63.3 (16)	59.2 (5)	60.0 (6)

[1]Only double-fin marks recorded by Oregon Fish Commission. Three LV and two RV marks recorded by State of Washington Department of Fisheries from fish landed in Washington ports are omitted.

[2]See Figure 1 for location of areas.

phenomenon, therefore the recoveries by area were grouped according to time rather than mark (Table 4). From July 16 to September 15 the smallest fish were always taken in the Swiftsure-Cape Flattery area. In all areas, except the Swiftsure-Cape Flattery area, the average size of the marked salmon recovered increased with time. The average length of salmon taken in the Swiftsure-Cape Flattery area only equalled that of other areas after September 15 when the homing migration brought salmon from all areas of the Pacific Ocean into the area.

During the June 1-July 15 period, salmon of the Swiftsure-Cape Flattery area were as large or larger than salmon taken in other areas (Table 4). This was mainly due to the relatively larger number of the D-RV group recovered from the area, and during this period the D-RV group were as large or larger than the marked salmon recovered from other areas (Table 1). Allen (1956) indicated that the D-RV group was later in average time of arrival into the Pacific Ocean, and that the D-RV group tended to migrate lesser distances north and south from the mouth of the Strait of Juan de Fuca than the other four groups. For the sake of discussion, we assume that the more vigorous, faster growing salmon will be the first to reach the Pacific Ocean, and that they will tend to migrate farther on reaching the ocean. If such were the case, the larger salmon of the later arriving D-RV group might have been more available to the troll fishery in the Swiftsure-Cape Flattery area during the June 1-July 15 period than were the other four groups which were ranging farther along the coast. The exact reasons for failure of the D-RV group to grow much beyond 60 centimeters are not known, but as previously noted must be related in some way to the effects of overrearing which they received at the Minter Creek hatchery.

DISCUSSION

There is no explanation at present for the differences in size at maturity attained by silver salmon feeding within Puget Sound and the Pacific Ocean. Intuitively one would not expect that all areas in the ocean which have temperature and salinity ranges acceptable to salmon would have comparable "pasturage" for these fish. Recent work by Aron (1958) using a modified Isaacs-Kidd mid-water trawl for the study of macroplankton and smaller nekton showed that there is a great variation with area in the relative abundance of the organisms which had been found by Allen and Aron (1958) to be of major importance in the diet of pink (*Oncorhynchus gorbuscha*), chum (*O. keta*), and sockeye salmon (*O. nerka*). The area covered by Aron (1958) included Puget Sound, Strait of Juan de Fuca, and the north Pacific Ocean extending from the coast of Washington to the Aleutian Islands. Prakash and Milne (1958) showed that there were differences in the feeding intensity (av-

TABLE 4.—*Average fork length (centimeters) of marked 1950-brood silver salmon recovered in the Pacific Ocean troll fisheries in 1953 by time and area of recovery* [Number of recoveries in parentheses]

Period of recovery	Average Length in Area of Recovery					
	West coast Vancouver Island	Swiftsure Bank Cape Flattery	Umatilla Reef La Push	Destruction Island	Grays Harbor	Oregon coast[1]
June 1 - July 15	53.7 (6)	56.7 (14)	58.8 (11)	51.3 (5)	57.7 (15)	62.1 (13)
July 16-31	61.7 (9)	53.3 (9)	61.0 (16)	58.0 (2)	57.9 (14)	61.1 (7)
August 1-15	63.7 (7)	56.2 (2)	61.4 (25)	62.3 (26)	66.0 (5)	62.0 (5)
August 16-31	63.7 (17)	62.2 (6)	63.4 (17)	63.2 (15)	66.8 (19)	57 (1)
September 1-15	65.9 (9)	59.0 (11)	68.2 (18)	73.7 (4)	71.2 (11)	74 (1)
September 15-October 30	67.8 (2)	67.3 (10)	65.2 (7)		70.7 (6)	
Average for entire season	62.7 (50)	59.0 (52)	64.1 (94)	62.2 (52)	64.1 (70)	62.1 (27)

[1]Only salmon released at Minter Creek included.

erage volume of food per centimeter of length) and in the type of food consumed (fish or crustacea) between silver salmon taken off the east and west coasts of Vancouver Island. Salmon taken from the east coast (Strait of Georgia) fed mainly on crustacea and had a lesser average volume per stomach than salmon taken off the west coast where the diet was predominately fish. Prakash and Milne state that known differences in oceanographic conditions could be expected to produce a difference in both quality and quantity of food available for silver salmon. Recent mid-water trawl studies on the standing crop of macroplankton within Puget Sound and closely adjoining regions conducted by the University of Washington Department of Oceanography have shown that the standing crop in certain areas of Puget Sound (*i.e.* Holmes Harbor, Port Susan, Hood Canal, Carr Inlet) was of the same order of magnitude as the standing crop in the open ocean adjacent to the Strait of Juan de Fuca (Aron, W., 1959, *personal communication*). Aron also reported that in both Puget Sound and the open ocean, the euphausiids are of prime importance, but the euphausiids in the two areas are different species, and that the mysid (*Neomysis Rayi*) was very abundant within the Straits of Juan de Fuca, especially the western end, but less common within Puget Sound. Euphausiids and mysids are known to undergo pronounced diurnal migrations and therefore might be less available than fish. Prakash and Milne (1958) indicated that the silver salmon off the west coast of Vancouver Island consumed mainly fish. If the species of fish consumed by the salmon were more abundant in the open ocean than in the inside waters, increased growth of the salmon in the open ocean might be related to a greater abundance of preferred food (fish), which presumably have a higher nutrient value per unit volume than crustaceans.

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Field Tests of Petersen, Streamer, and Spaghetti Tags on Striped Bass, Roccus saxatilis (Walbaum)[1]

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ABSTRACT

Tagging experiments were conducted in northeastern North Carolina during 1955 and 1956 to select a tag suitable for use in brackish waters for studying population dynamics and movements of striped bass. The following tag comparisons were carried out: streamer and Petersen, streamer and soft spaghetti, and streamer and hard spaghetti. Observations were made on recovery of tags as related to size of fish, length of time tagged, selectivity of tagged fish by commercial gear, and durability of tags. The streamer tag was selected from those tested as the one best suited for future use.

INTRODUCTION

As part of a co-operative investigation[1], United States Fish and Wildlife Service biologists, working under authorization of the Saltonstall-Kennedy Act, applied Petersen, streamer, and spaghetti tags to striped bass in the Albemarle Sound-Roanoke River region of North Carolina during the fall fishing season of 1955 and the spring and fall seasons of 1956. The three types of tags were applied in order to select one tag type that would be satisfactory for studying population dynamics and movements of striped bass in that area. The suitability of a tag type for such a study depends upon its 1) not being shed easily, 2) permitting fish growth, 3) not altering the natural activity or catchability of a fish, and 4) being easily recognizable by fishermen when fish are removed from the water.

Literature on the types of tags and tagging materials used on striped bass prior to 1952 reviewed by Raney (1952) indicated that two of the most satisfactory tags were the internal tag and the Petersen disk. Calhoun (1952) described a study of the migration of spawning striped bass in which Petersen tags were applied under the first dorsal fin and on the caudal peduncle. Aquarium tests with striped bass (Calhoun, 1953) showed Petersen disks, located under the first dorsal fin and on the caudal peduncle, to be the most satisfactory for general use. Opercle type tags and a single Atkins type tag attached with heavy braided nylon were both unsatisfactory. Other Atkins tags attached by wire were surprisingly successful, and a staple tag incorporating features of Atkins and Petersen types was developed but not adequately tested. Two jaw tags, one a metal strip bent in the shape of a ring and the other a split wire ring with a vinylite tag, are pictured, described, and reported as used in striped bass in Canadian waters (Conseil Permanent International Pour l'Exploration de la Mer, 1953). A field test of three different metals in pins used to attach Petersen tags to the caudal peduncle of striped bass showed that tantalum and dead soft stainless steel were comparable and better than other metals (Skinner and Calhoun, 1954).

Two types of Atkins tags, a streamer type and a spaghetti type, were considered for use on striped bass in the present experiment. One form of the streamer tag is described by Alverson and Chenoweth (1951). They concluded from water tunnel tests that this type of tag showed promise for use on tuna-like fishes. Wilson (1953) describes four other modifications of the streamer which were discarded because the small bearing surface made the

[1]Co-operating in the study are the North Carolina Wildlife Resources Commission; North Carolina State Stream Sanitation Committee; North Carolina State College; North Carolina Department of Conservation and Development; Institute of Fisheries Research of the University of North Carolina; United States Public Health Service; United States Army, Corps of Engineers; Southeastern Power Administration; National Council for Stream Improvement; Halifax Paper Company; North Carolina Pulp Company; and Virginia Electric and Power Company.

possibility of shedding high. There was no positive evidence of excessive loss, however, for the one type that was actually field tested on yellowfin tuna. Joeris (1953) describes and illustrates a technique for the application of a streamer-type fish tag. Eschmeyer, *et al.* (1953) discusses some possible causes for different rates of return for Petersen, streamer, and jaw tags. Eschmeyer (1959) describes comparisons made between Petersen, streamer, cheek, and jaw tags and fin clips as marking devices for lake trout in rearing ponds and in Lake Superior. Wilson (*op. cit.*) describes five types of spaghetti tags and the results of field trials with them. Collyer (1954) tested four types of spaghetti tags in a water tunnel, on the bottom of a vessel, and by tagging yellowtail (*Seriola dorsalis*) at sea. The only fault observed was that sunlight apparently caused the ink in the legend to fade. As a result, a new ink formula was developed. Large scale tuna tagging with spaghetti tags in the Pacific Ocean has been reported in Commercial Fisheries Reviews (U. S. Fish and Wildlife Service, 1954, 1955, 1956, and 1957). Spaghetti tags have been aquarium tested on largemouth bass and brown bullheads (Kimsey, 1956) and field tested on largemouth bass (Tebo, 1957).

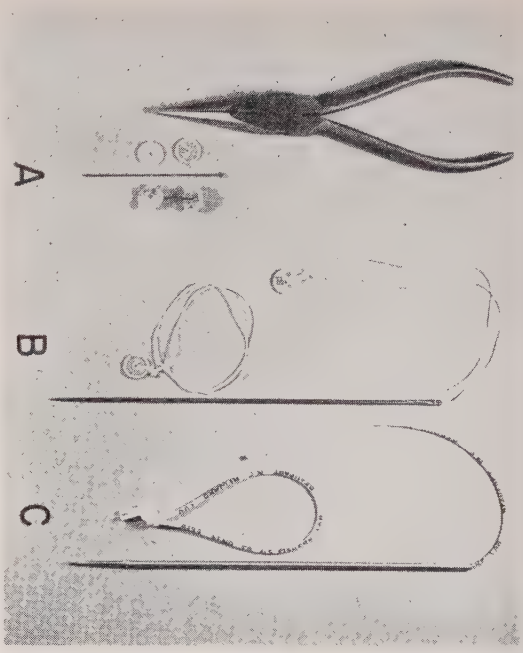

FIGURE 1.—Tag components and tools used in their application for: A—Petersen tag, B—streamer tag, and C—soft spaghetti tag. The hard spaghetti tag was different from the soft spaghetti tag only in the composition of the plastic. Figure on right in A and the lower figures in B and C show tags knotted as though they had been applied to fish.

MATERIALS AND METHODS

Tags and methods of application

The Petersen tag used in the present study consisted of two 7/16-inch diameter red plastic disks (0.0375 inches thick, 0.038-inch diameter hole with a clear plastic overlay to protect the ink). Disks were manufactured by Howitt Plastics Company, Route 2, Box 61-B, Molalla, Oregon. One disk was blank and the other bore an identifying number on one side and an address and reward notice on the other (Figure 1-A). The tag was attached by inserting a stainless steel pin through the flesh of the fish under the spinous dorsal fin.

The streamer tag was composed of a single red plastic disk, 7/16-inch in diameter, which bore a number on one side and an address and reward notice on the other, to which a loop of nylon net twine (No. 139, Linen Thread Company) was tied (Figure 1-B). The tie was formed by making a crossed running knot (R. J. Ederer Co., 1948), passing the ends around the loop and making a square knot, and then fusing the ends together with a candle flame. The nylon loop was sewed through the flesh of the fish under the soft dorsal fin by means of a 7-inch carpet needle having a notched eye (Figure 1-B). The disk was then passed through the loop, and a simple overhand knot was tied as near the tag as possible. When the fish was released, the disk trailed along the dorsal side of the caudal peduncle.

The hard spaghetti tag was made from a single piece of white vinylite tubing 12 inches long (No. 20, XTE-30, 0.0625 inch outside diameter, manufactured by C. D. LaMaree, 1325 San Julian Street, Los Angeles, California). The identifying number and an address and reward notice were printed by hand on its surface with vinylite black ink (No. 104N-5A4, manufactured by California Ink Co., 2939 East Pico Blvd., Los Angeles, California). This tag was inserted through the flesh of the fish under the soft dorsal fin by means of a solid pointed hollow needle 7 inches long and 0.120 inch in outside diameter (Figure 1-C). The two ends were tied together in a figure-

eight knot which trailed over the caudal peduncle in a position similar to the disk of the streamer tag.

The soft spaghetti tag was made from a single piece of white ivi-flex tubing 12 inches long (Figure 1-C). This tubing was described as compound 6539, size 20, inside diameter 0.034 inches, outside diameter 0.066 inches, by the Plastics Division of Irvington Varnish and Insulator, Irvington 11, New Jersey. The identifying number and an address and reward notice were printed by hand on its surface with vinylite black ink. This tag was applied to striped bass on the same part of the body and by the same method as the hard spaghetti tag.

Classification of recovery gear

All tags were subject to recovery by six different commercial and sport fishing gears in northeastern North Carolina. These gears were classified into two categories. The first group, which included pound nets, purse nets, haul seines, hoop nets, and hook and line, was termed non-selective because tags would not be likely to cause the capture of fish by becoming entangled in these gears. The second group, which included only gill nets (3½- to 6½-inch stretched mesh), was termed selective because there was a possibility that tags could become entangled with net twine and cause the capture of fish that would have escaped had they not been tagged.

Methods of collecting recovered tags

A reward of one dollar was paid for the return of each tag. Fish dealers who co-operated by buying tags from fishermen and individual fishermen were contacted weekly for tags during months when tagging was in progress.

After completion of tagging for a season, fish dealers were contacted monthly to collect recovered tags. Tags were also returned by mail according to the instructions printed on them.

PHYSICAL CHARACTERISTICS OF STUDY AREA

Albemarle Sound and three small adjoining sounds, Currituck, Croatan, and Roanoke, form a continuous body of water about 57 miles long and from 3½ to 14 miles in width. It is fed by nine principal tributaries, and is separated from the Atlantic Ocean by the outer banks of North Carolina except for a narrow passage called Oregon Inlet. Salinities in Albemarle Sound change from a general concentration of 0.3 parts per thousand in the western end to a general concentration of 6 parts per thousand in the eastern (G. S. Posner, personal communication, 1958)[2]. Posner also has noted salinities generally as high as 14 parts per thousand on the western side of the outer banks and in Roanoke Sound proper. Roelofs and Bumpus (1953) indicate possible salinities as high as 18 parts per thousand in the southern part of Roanoke Sound, and Marshall (1951) found salinities of 19 parts per thousand in southern Croatan Sound. The salinities of Currituck Sound varied from an average of 2.5 parts per thousand in the northern end to an average of 10.5 parts per thousand in the southern end during the spring, summer, and fall of 1955 (Dickson, 1955).[3]

The Roanoke River empties into the western end of Albemarle Sound. Water velocities and levels in the river fluctuate in response to runoff and power manufacturing requirements at and above Roanoke Rapids, North Carolina. Waste from a paper manufacturing plant at Roanoke Rapids and another at Plymouth, North Carolina, is emptied into the river. The Roanoke Rapids Dam, located about 137 river miles from the mouth, is the upstream limit of fish movement.

THE STRIPED BASS FISHERY

The commercial catch of striped bass in Albemarle Sound has been approximately 600,000 pounds annually for the past several years. This annual yield is composed of large fall and spring catches and a small midwinter catch. Commercial fishermen begin setting nets in Albemarle Sound during late September or October. As the catch of striped bass increases, fishing pressure increases until a peak is reached in November or December. When catches are high during the fall season, nets are fished continuously; but when the rate of catch falls off, fishing effort drops until catches pick up again. Purse netting is usually concluded by the first of December, pound netting

[2]Oceanographer with Institute of Fisheries Research, University of North Carolina.

[3]Arthur W. Dickson. 1955. Salinity variations in Currituck Sound (March. 1955-November, 1955). Job No. 1 (in part) of Dingell-Johnson Project F-5-R, North Carolina Wildlife Resources Commission.

by the middle of December, gill netting (3½- to 4½-inch stretched mesh) and haul seining are usually greatly reduced by the last of December. During some years, however, the gill net fishery is operated through January. The largest number of fishermen use gill nets, while a much smaller number use pound nets. There are less than ten each of purse netters and haul seiners in the whole area. The start of the annual migration of shad and herring in late January and early February results in renewed effort by fishermen using gill nets of 5½-inch stretched mesh, pound nets, and haul seines. Striped bass are caught in this fishery until the season officially closes the first of May. There are also fall and spring sport fisheries for striped bass in Albemarle Sound.

A concentrated sport fishery, in which hook and line and bow nets are used for the capture of striped bass, is carried on in the Roanoke River during April and May in the vicinity of Weldon, North Carolina between river mile 120 and 138. Some trot lines are used in the lower 90 miles of the river at the same time. During April, one haul seine and a few drift gill nets and fyke nets are operated within the 60-mile section between Hamilton, North Carolina, and the mouth of the river.

TAG RETURNS FROM VARIOUS SIZE-CLASSES OF FISH

Petersen and streamer tagging in fall of 1955

Petersen and streamer tags were applied to striped bass caught by commercial fishermen in pound nets and gill nets in Albemarle Sound from October through December of 1955. Tagged fish were released immediately at the site of capture. In a total of 25 tagging trips, both streamer and Petersen tags were placed on striped bass during 9 trips; Petersen tags were applied exclusively during 14 trips; and streamer tags were applied exclusively on 2 trips. The method recommended by Rounsfell and Kask (1945) of tagging alternate fish with a different type of tag was followed. Small numbers of fish on each tagging day and a wide range in size classes of fish resulted in disproportionate marking by 1-inch size interval by

TABLE 1.—*Comparative return of streamer and Petersen tags from striped bass tagged alternately with these two tags and retaken by commercial fishing in Albemarle Sound*

Size class—fork length in inches	Streamer tags			Petersen tags		
	Number of tags applied	Classifiable returns		Number of tags applied	Classifiable returns	
		Gill nets[1]	Non-selective gear[2]		Gill nets[1]	Non-selective gear[2]
≤ 9	3	–	1	1	1	–
10	7	2	1	6	4	–
11	23	6	6	20	12	3
12	29	8	2	32	20	2
13	10	4	3	12	7	1
14	17	7	1	12	6	2
15	17	9	3	15	5	–
16	8	2	2	6	3	–
17	–	–	–	3	2	–
≥18	7	1	–	6	1	2
Totals	121	39	19	113	61	10
Unclassifiable returns		5			2	
Total returns		63			73	
Percentage returns		52			65	

[1] 3.5- to 5.5-inch stretch mesh.
[2] Pound nets, purse nets, haul seines, hoop nets, hook and line.

days, but nearly proportionate marking by 1-inch size interval for the entire tagging period (Table 1).

Table 1 shows that of 121 streamer tags and 113 Petersen tags applied alternately, 52 percent of the former and 64 percent of the latter were returned. Of 428 Petersen tags applied exclusively, 63 percent were returned (Table 2). The returns from these applications were separated into twelve categories and tested as follows.

Numbers of returns by size class for tags recovered by selective gear for the two types of tags differ widely below the 13-inch size class (Total for classifiable returns, Table 1). A chi-square test at the 95 percent level shows that for Petersen tags and streamer tags applied alternately, a significantly greater number of Petersen tags were recovered from fish less than 13 inches fork length caught in selective gear. There was no significant difference in the number of Petersen and streamer tags recovered which had been applied alternately in the following categories: 1) fish equal to and greater than 13 inches fork length recaptured in selective gear, 2) fish less than 13

TABLE 2.—*Returns from 428 Petersen tags applied to striped bass in Albemarle Sound and retaken in the commercial fishery.*

Size class—fork length in inches	Number tagged	Classifiable returns	
		Gill nets[1]	Non-selective gear[1]
≤ 9	16	9	–
10	49	27	2
11	82	44	4
12	87	56	4
13	45	29	2
14	27	9	–
15	56	32	2
16	36	13	4
17	10	5	–
≥ 18	20	3	3
Totals	428	227	21
Unclassifiable returns		20	
Total returns		268	
Percentage return		63	

[1]See footnotes to Table 1.

TABLE 3.—*Comparative return of streamer and hard spaghetti tags from striped bass retaken by commercial fishing in Albemarle Sound*

Size class—fork length in inches	Streamer tags			Hard spaghetti tags		
	Number tagged	Classifiable returns		Number tagged	Classifiable returns	
		Gill nets[1]	Non-selective gear[1]		Gill nets	Non-selective gear
≤ 11	10	2	1	9	–	–
12	8	2	1	8	1	–
13	6	1	–	5	–	2
14	15	1	1	18	1	2
15	22	4	3	19	1	2
16	21	1	2	21	2	1
17	7	–	2	6	1	2
18	10	3	–	9	–	3
19	6	–	3	6	–	3
≥ 20	27	–	4	24	3	2
Totals	132	14	17	125	9	17
Unclassifiable returns		7			9	
Total returns		38			35	
Percentage return		29			28	

[1]See footnotes to Table 1.

inches fork length recaptured in non-selective gear, and 3) fish equal to and greater than 13 inches fork length recaptured in non-selective gear. There was no significant difference between the number of Petersen tags applied alternately and the number of Petersen tags applied exclusively (Tables 1 and 2) recovered from fish in any of the following categories 1) fish less than 13 inches fork length recaptured in selective gear, 2) fish equal to and greater than 13 inches fork length recaptured in selective gear, 3) fish less than 13 inches fork length recaptured in non-selective gear, and 4) fish equal to and greater than 13 inches fork length recaptured in non-selective gear.

Other chi-square tests (95 percent level) were made including returns which could not be classified as to recovery gear, as well as returns made from selective gear and returns made from non-selective gear (Total returns, Tables 1 and 2). The addition of the non-classifiable returns did not change the relationships shown in the preceding paragraph between streamer and Petersen tags applied alternately, or between Petersen tags applied alternately and Petersen tags applied exclusively.

Fishermen reported frequent tangling of the pins and disks of Petersen tags with gill net twine and very little tangling of streamer tags. They also reported occasionally finding only a Petersen tag tangled in their nets from which the fish bearing the tag had probably torn free and escaped.

The only significant difference found in these tests was between the number of returns of Petersen and streamer tags applied alternately and recovered from striped bass less than 13 inches fork length. This strongly indicates that small fish bearing Petersen tags are more likely to be caught in gill nets than those bearing streamer tags. This conclusion is supported by reports from fishermen concerning tags tangling in their nets.

Streamer and hard spaghetti tagging in spring of 1956

Streamer and hard spaghetti tags were applied to striped bass which were captured

TABLE 4.—*Comparative returns of streamer and soft spaghetti tags from striped bass retaken in commercial gear in Albemarle Sound after proportionate and disproportionate (enclosed by parentheses) application of tags of the two types*

Size class—fork length in inches	Streamer tags			Soft spaghetti tags		
	Number tagged	Classifiable returns		Number tagged	Classifiable returns	
		Gill nets[1]	Non-selective gear[1]		Gill nets	Non-selective gear
≤ 9	7 (–)	1 (–)	– (–)	2 (–)	– (–)	– (–)
10	– (–)	– (–)	– (–)	2 (–)	– (–)	– (–)
11	25 (2)	1 (–)	1 (–)	25 (–)	– (–)	2 (–)
12	84 (10)	14 (–)	2 (–)	84 (1)	6 (–)	4 (–)
13	86 (16)	13 (7)	2 (–)	82 (11)	19 (3)	3 (–)
14	21 (27)	9 (8)	1 (–)	21 (22)	5 (6)	– (–)
15	37 (137)	10 (40)	3 (11)	34 (61)	8 (16)	2 (4)
16	30 (105)	11 (24)	– (6)	32 (71)	7 (19)	1 (8)
17	11 (24)	2 (8)	– (1)	8 (14)	1 (2)	– (1)
≥ 18	15 (18)	1 (6)	2 (–)	10 (3)	1 (2)	1 (–)
Totals	317 (339)	62 (93)	11 (18)	300 (183)	47 (48)	13 (13)
Unclassifiable returns		27 (37)			22 (18)	
Total returns		100 (148)			82 (79)	
Percentage return		32 (44)			27 (43)	

[1]See footnotes to Table 1.

during April and May of 1956 in the Roanoke River by means of a haul seine, a trap similar to that described by Hallock, *et al.* 1957), and bow nets. Tagged fish were released immediately at the site of capture.

In order to insure application of equal numbers of both tags by size class of fish, a special form was developed for use in the field as a guide. This form, a copy of which is available upon request, makes it possible to establish a predictable minimum difference between the number of two types of tags applied each tagging day in every size class. The magnitude of that difference is dependent upon many uncontrollable factors if alternate fish are tagged with different tag types.

When more than one fish was tagged in a given 1-inch size interval in a given day, the two types of tags were applied alternately in that size class. On many days, however, only one fish was tagged in each of several size classes. For this reason tags were applied disproportionately by size class by days, but proportionately by size class for the entire tagging period.

There was a total of 132 streamer tags applied with a return of 29 percent, and a total of 125 hard spaghetti tags applied with a return of 28 percent (Table 3). No significant difference at the 95 percent level was found by means of the chi-square test between returns of streamer and hard spaghetti tags (Table 3) in any of the following categories: 1) fish below 13 inches fork length recaptured in selective gear, 2) fish below 13 inches fork length recaptured in non-selective gear, 3) fish 13 inches and longer recaptured in selective gear, and 4) fish 13 inches and longer recaptured in non-selective gear.

Two additional comparisons were made in which total returns for streamer tags and total returns for hard spaghetti tags (Table 3) were separated into the following categories: 1) returns from fish below 13 inches fork length, and 2) returns from fish equal to and greater than 13 inches fork length.

A correction term, n/2, was used in all chi-square tests to adjust for discontinuous data in small samples (Snedecor, 1957, p. 221). This adjustment changes a chi-square value, which is significant at the 95 percent level when arrived at by the usual formula, to a non-significant value for the difference between total returns of streamer and hard spaghetti tags from fish below 13 inches fork length. There was no difference in returns of streamer and of hard spaghetti tags from fish equal to and greater than 13 inches fork length. There have been only a few reports by fishermen of fish tagged with streamer tags being held by the disk in gill nets, and there have been no reports of spaghetti tags tangling with gill net twine.

It can be concluded from the Roanoke River tagging that streamer tags were not significantly different from hard spaghetti tags as far as gear selectivity was concerned.

Streamer and soft spaghetti tagging in fall of 1956

Streamer and soft spaghetti tags were applied to striped bass captured in gill nets, pound nets, and haul seines fished in Albemarle Sound during October, November, and December of 1956. It was necessary to obtain most of the fish for tagging from gill nets during the fall of 1956, because pound nets were much less successful that season than they had been during the 1955 fall season. Tagged fish were released immediately at the site of capture.

A total application of 656 streamer tags and 483 soft spaghetti tags yielded 38 percent and 33 percent return respectively. Table 4 shows numbers of fish by size classes tagged with streamer and soft spaghetti tags when tagging was guided by the form mentioned (resulting in proportionate tagging) and when the form was not used (resulting in disproportionate tagging). No significant difference (chi-square test, 95 percent level was found for recoveries in either selective or non-selective gear between 1) streamer and soft spaghetti tags applied proportionately for fish less than 13 inches fork length, 2) streamer and soft spaghetti tags applied proportionately for fish tive gear were compared (chi-square test, 95 percent level) between streamer and soft spag- equal to and greater than 13 inches fork length, 3) streamer and soft spaghetti tags applied disproportionately for fish equal to and greater than 13 inches fork length (the only size classes that could be tested, Table 3), 4) streamer tags applied proportionately and streamer tags applied disproportionately for fish equal to and greater than 13 inches fork length, and 5) soft sphagetti tags applied proportionately and soft spaghetti tags applied disproportionately for fish equal to and greater than 13 inches fork length.

Total returns (Table 4), including those not classifiable as to recovery gear, as well as returns from selective gear and returns from non-selec-

tive gear, were compared (chi-square test, 95 percent level) between streamer and soft spaghetti tags. There was no change in the relationships between these tags listed in the preceding paragraph. Adjusting for discontinuous data in small samples, a chi-square value, significant at the 95 percent level when arrived at by the usual formula, is changed to a non-significant value for the difference between total classifiable returns of streamer and soft spaghetti tags which had been applied proportionately to fish below 13 inches fork length and were recaptured in selective gear.

It must be concluded from the 1956 Albemarle Sound tagging that streamer tags were not different from soft spaghetti tags as far as tag selectivity was concerned.

RETURNS COMPARED BY LENGTH OF TIME FREE

It was necessary to make a decision on the advisability of using Petersen or streamer tags based on selectivity of returns between the middle of December, 1955, when the last tags were applied, and the middle of March, 1956, when preparations were started for the Roanoke River tagging. The decision was based on all tags recovered up to that time which were classifiable as to recovery gear. Chi-square tests (95 percent level), however, show that if only returns from fish which had been free up to 49 days before recapture had been used (representing 26 percent and 50 percent recaptures for streamer and Petersen tags respectively), the same decision would have been reached as was reached after 91 days and was still accurate at the end of the experiment.

The time lapse from date of tagging to date of recovery, before the relationship emerged concerning the selectivity of streamer and soft spaghetti tags in 1956, was similar to that in the 1955 comparisons. Chi-square tests (95 percent level) again show that if only the tags returned from fish which had been free up to 49 days before recapture had been used to compare tag selectivity (representing 11 percent recaptures for both tag types), the same relationship between tag types would have been shown as was shown by the addition of the returns for each successive time interval until the termination of the experiment.

Only a small part of all gear used in the Roanoke River is selective. Adequate returns for comparative purposes from selective gear of tags applied in the Roanoke River were not forthcoming until the fall of 1956. Therefore, the spring, 1956, tagging did not lend itself to an early analysis for selectivity, and tag returns cannot be compared on the basis of the length of time they were free as was done in the two preceding paragraphs.

DURABILITY OF TAGS

Tags on fish that had been free from one fishing season to the next, at least 250 days, were recovered for each tag type. From the 1955 fall tagging, 0.5 percent (1) of the available fish bearing Petersen tags (203) and 6.5 percent (4) of the available fish bearing streamer tags (62) were recaptured the following fall. A chi-square test at the 95 percent level shows this to be a significant difference. All of these streamer tags were recovered from fish that were less than 13 inches fork length when tagged, and the Petersen tag was recovered from a fish 15 inches in fork length when tagged. Of the 1956 Roanoke River spring tagging, 11.3 percent (12) of the available fish bearing streamer tags (106) and 15.9 percent (17) of those bearing hard spaghetti tags (107) were recaptured during the late winter and spring of the following year. There was no significant difference between these returns (chi-square test, 95 percent level). Only one of the streamer tags was recovered from a fish that had been less than 13 inches fork length when tagged, and none of the hard spaghetti tags were recovered from fish that were less than 14 inches fork length at the time of tagging. From the fall, 1956, tagging, 3.5 percent (15) and 4.7 percent (16) respectively of the available streamer (423) and soft spaghetti (338) tags were returned the following fall. A significant difference with the chi-square test at the 95 percent level cannot be shown between these returns. Five streamer and six soft spaghetti tags were returned from fish that had been less than 13 inches fork length when tagged.

The longest period between tagging and recapture for each of the four tag types tested was: Petersen—349 days, soft spaghetti—431 days, streamer—447 days, and hard spaghetti—556 days.

The durability of streamer and both spaghetti tags appears to be similar and better than that of Petersen tags when used on striped bass in the Albemarle Sound-Roanoke River area of North Carolina.

CONDITION OF RECOVERED TAGS AND RECAPTURED FISH

Occasionally a hydroid growth was found

FIGURE 2.—Hydroid growth accumulated on a soft spaghetti tag (top) and hard spaghetti tag (bottom) which were free 426 and 451 days respectively. Failure of the tagger to clip ends from the upper tag may be responsible for the large hydroid growth thereon. Sores are visible at the point of tag insertion, but both fish appeared to be in good condition otherwise.

or reported on the streamer and spaghetti tags (Figure 2). When recovered tags were examined at the laboratory, fragments of the hydroid growth were found around the knots of 11 hard spaghetti tags, 4 soft spaghetti tags, and 1 streamer tag. Since the nylon thread to which the material was attached and the disk of the streamer tag were often separated before the disk was returned to the laboratory, and spaghetti tags were frequently cleaned before they were collected, the frequency of these growths could not be determined. Only four of the sixteen tags which bore evidence of the hydroid growth had been in the water less than 300 days. The shortest period between tagging and recovery for any of these tags was 151 days for a soft spaghetti tag.

Vinylite black ink, used to inscribe the legend on spaghetti tags, was sometimes affected by contact with the flesh of striped bass. The legend on that part of the tag which remained in contact with the flesh of the fish became illegible. Of the tags returned, 25 hard spaghetti and 14 soft spaghetti tags were affected in this way. None of these tags had been on a fish less than 159 days, and the majority of them had been on fish for more than 300 days.

Twenty-six of the hard spaghetti tags and 19 soft spaghetti tags were noticeably harder, to the point of brittleness in some cases, when they were returned than they had been when applied. The shortest period between tagging and recapture before hardening was 123 days, while most of the tags that changed texture remained in the water for more than 300 days. No knots had come untied or loosened, and no breakage of brittle plastic had occurred among the tags returned.

The author examined three striped bass bearing streamer tags immediately after their recapture in the Roanoke River. Each of these fish had a raw spot on the caudal peduncle beneath the disk. If the knot had been tied as much as two inches away from the disk, there was another raw spot under the knot. These sore spots were not observed on fish recaptured in Albemarle Sound. Vigorous swimming movements by the fish, brought about by the 100- to 137-mile migration and spawning activity in the rather swift flowing Roanoke River, may have been responsible for the abrasive effect of the tag.

The method used to collect recovered tags from fishermen made it difficult for biologists to obtain recaptured fish for examination. Many fishermen were questioned, however, concerning sores on striped bass caught by tag application or by the tag itself. Fishermen who had noted the condition of the fish reported that tagging wounds had healed, or at least that no appreciable injury was evident. Sores at the point of tag insertion were noted on one fish that had been tagged considerably more than the usual quarter-inch below the dorsal surface with a soft spaghetti tag. No sores at the point of tag insertion were observed that were larger than those shown in Figure 2.

Among the tags recovered, three streamer and one soft spaghetti retained fragments of fish flesh, evidently the result of the tagging wound healing completely. These tags had been on striped bass from 153 to 381 days.

CONCLUSIONS

Results from three tagging seasons over a 2-year period permit the following conclusions:

1) Striped bass bearing streamer tags were recaptured less selectively by gill nets than those bearing Petersen tags in size classes below 13 inches fork length.
2) There was no significant difference in the recovery of streamer tags and hard spaghetti tags by size of fish and type of recapture gear.
3) There was no significant difference in the recovery of streamer tags and soft spaghetti tags by size of fish and type of recapture gear.
4) The streamer tag was more legible and less subject to physical and chemical change than either type of spaghetti tag.
5) The durability of the streamer tag and both types of spaghetti tags was comparable and better than that of the Petersen tag.
6) The streamer tag was selected as the most satisfactory of the four tags tested for future studies.

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Food of Yellow Perch, Perca flavescens (Mitchill) in Saginaw Bay, Lake Huron[1]

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In Saginaw Bay, Lake Huron, an abundant population of yellow perch has provided a substantial commercial fishery. The commercial catch of this species averaged nearly 400,000 pounds for the years 1950-1955. Due to its importance, the Fish and Wildlife Service and other agencies have been investigating various aspects of the biology of the yellow perch in Saginaw Bay and elsewhere in the Great Lakes. This paper is a summary of a study of the food habits of this species in Saginaw Bay, Lake Huron.

The yellow perch used in this study were collected from 4 different stations (1 station was visited twice) between August and October 1956 as part of a fishery survey conducted by the Fish and Wildlife Service with its research vessel *Cisco*. All of the fish were caught in a modified shrimp trawl in water 3 to 10½ fathoms deep. The trawl was lowered to the bottom and towed for 5 to 30 minutes, usually parallel to the bottom contour, at approximately 3 miles per hour. A random sample of perch captured at each locality was preserved in 10-percent formalin. The total sample for the 4 localities was 241 fish. After preservation, total length was measured to the nearest 0.1 inch and sex of each fish was determined. Stomach contents were transferred to numbered vials. Quantitative determinations following the methods of Surber (1930) were made by means of a piece of plastic divided into square sections (25 squares to the inch) as a counting grid. Volumetric measurements of each kind of food (whole organisms and fragments) were made by water displacements in a centrifuge tube, graduated to 0.1 milliliter. Identifications of animals were made to the lowest taxonomic category possible. Miscellaneous plant remains and items that were taken incidentally in feeding (coal, sand, pebbles, . . .) were all classed as "non-food."

The lengths of the yellow perch ranged from 2.5 to 8.3 inches. The most common length interval was 5.0-5.4 inches. The samples showed a multimodal length distribution with only 1 fish between 3.0 and 3.9 inches. The lack of perch in this interval was probably due to the scarcity of fish of this size at this time of year in Saginaw Bay. El-Zarka (1959) found that Saginaw Bay perch averaged 2.7 inches (males) and 2.8 inches (females) at the end of the first year of life, and attained 4.2 inches and 4.3 inches respectively by the end of the second year. Since growth is most rapid during the summer, most of the fish that were 3.0-3.9 inches long (yearlings) in the late spring would have grown out of this group by the end of summer. Likewise, young of the year would not yet have attained a length of 3.0 inches at the time of collection.

Immature insects were the dominant items in the stomachs of the Saginaw Bay yellow perch. Of the 241 stomachs examined, 170 contained food; insects, primarily tendipedid larvae and pupae, and mayfly nymphs, were found in 82 percent of the stomachs and comprised 26 percent of the total food volume. Next in importance were cladocerans (*Daphnia, Sida, Holopedium, Alona*). They occurred in 50 percent of the stomachs and comprised 22 percent of the total volume, even though they were present in the perch at only 3 stations. Although amphipods, principally *Gammarus,* were present in 2 to 76 percent of the stomachs at all collecting localities, they formed a substantial part of the food volume (22 per-

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cent) at only one locale. Snails (*Physa, Valvata*) and fingernail clams (*Pisidium*) appeared in about equal numbers at 4 stations and accounted for approximately 6 percent of the total food volume.

Copepods (*Cyclops, Diaptomus*) were frequent, especially in the stomachs of the perch less than 3.0 inches long taken at one station (41-percent occurrence). Water mites were present in large numbers in stomachs from perch taken at 3 localities (1 stomach contained 91 mites) but comprised only 1 percent of the total volume of stomach contents. Ostracods were eaten in small numbers at 4 stations. Isopods were found in only 4 individuals. Fish were of relatively minor numerical importance in the diet of the perch (in only 6 percent of the stomachs). Sand, pebbles, coal, and bits of plant material occurred in 39 percent of the stomachs.

When the results were tabulated according to length irrespective of collection localities, differences in the food habits of the various size groups were apparent. Immature insects were prominent as food for all of the groups; however, mayfly nymphs, which were the largest insects available, occurred only in the stomachs of perch longer than 4.7 inches. Smaller crustaceans, especially cladocerans and copepods, were eaten in large numbers by 2.5- to 5.4-inch individuals. Larger amphipods, water mites, clams, and snails occurred more frequently in fish 4.5 inches or more in length Copepods were the chief constituents in the food of the young of the year (2.5-2.9 inches), but were absent from the stomachs of perch more than 5.4 inches long. Fish (*Osmerus mordax, Alosa pseudoharengus*) first appeared in the stomachs of 4.0-inch perch and made up a progressively greater part of the diet with increase in size of the perch. Although the samples included no perch more than 8.3 inches long, it is considered probable that fish may constitute the principal food of larger perch. The smelt and the alewife are frequent associates of the perch in Saginaw Bay, and, because of their abundance, may be the principal food of larger perch (El-Zarka, 1959).

Some differences in the food habits of the sexes were discovered. Of the 11 yellow perch stomachs that contained fish, 9 were from females and 2 were from males although males outnumbered the females more than 2 to 1 in the samples (116 males, 54 females). Conversely, nymphs of the mayfly *Hexagenia*, a burrowing form, were present more often in males (18) than females (8). This evidence suggests that the males had been feeding mainly on the bottom, whereas the females fed in the open water as well as on the bottom. The yellow perch is thought to school by sexes (Eschmeyer 1938; Weller 1938; Jobes 1952; and others). Eschmeyer concluded that in Ford Lake, Michigan, the distribution of the sexes was determined by the distribution of the preferred food—that females occurred predominantly in the shallows where minnows were abundant whereas the males congregated in the deeper waters and fed largely on midge larvae.

Nine species of fish were collected with the yellow perch in Saginaw Bay, but only 2, the alewife and the smelt, were taken at all of the stations. The alewife formed as much as 96 percent (by numbers of individuals) of the catch of associated species at one station. The alewife appeared in greater numbers toward the middle of September, whereas the smelt decreased then to only a small fraction of its earlier abundance. At one station only 2 adult smelt were taken in September, whereas a month earlier over 1,000 were caught at this same locality. Other fish taken with the perch in the trawls were the emerald shiner (*Notropis atherinoides*), spottail shiner (*Notropis hudsonius*), troutperch (*Percopsis omiscomaycus*), logperch (*Percina caprodes*), white sucker (*Catostomus commersoni*), black crappie (*Pomoxis nigromaculatus*), and channel catfish (*Ictaluris punctatus*).

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Elasticity of Growth of Yellow Perch, Chain Pickerel, and Largemouth Bass in Some Reclaimed Massachussetts Waters

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ABSTRACT

To evaluate the Massachusetts warm-water pond and lake reclamation program, which began in 1952, age and growth studies were made on several species of fish. After reclamation by rotenone, growth rates of yellow perch, chain pickerel, and largemouth bass were found to be more rapid than under natural conditions and in some cases growth rates exceeded those recorded in the literature. Adult fish stocked after reclamation showed marked increase in growth, as did resident adult fish remaining after thinning of the population. Rapid growth in reclaimed waters is attributed to reduced competition for food because of lower population densities. In these ponds it appears that the rate of growth of yellow perch, chain pickerel, and largemouth bass was more dependent upon population density than upon length of growing season or other factors.

INTRODUCTION

During 1951 and 1952, a statewide fishery reconnaissance survey of 132 ponds showed only about 26 percent to be in a state of balance considered capable of producing good fishing (Stroud, 1955). These findings have been substantiated by more recent intensive studies on selected Massachusetts waters in which overcrowding by pan and trash fishes appears to be the principal reason for poor quality of fishing. This overcrowding has been brought about, at least partly, by indiscriminate stocking in the past and by selective angling whereby the larger fish are removed.

Nets and chemicals (principally rotenone) have been used to renovate the non-productive fish populations by partial or complete eradication of existing fish populations. When complete eradication was achieved, a simplified combination of desirable fishes was restocked after the pond had become non-toxic. Some of the combinations that have been stocked are largemouth bass, yellow perch and brown bullhead: chain pickerel and yellow perch; largemouth bass and alewives; and chain pickerel and alewives.

Fyke-net thinning of fish populations (Grice, 1957) resulted in increased growth only for those species being thinned (mostly panfishes) and there was no apparent increase in the numbers or weight of gamefish. More drastic rotenone thinning resulted in increased growth of all species including gamefishes.

During the age-and-growth studies conducted on both pre- and post-management fish populations, it became apparent that the growth of some species of fish in newly-reclaimed waters was very rapid, far exceeding state-average growth rates, and in some cases exceeding growth rates reported from most sections of the country. This paper considers growth rates of yellow perch, *Perca flavescens;* chain pickerel, *Esox niger;* and largemouth bass, *Micropteris salmoides.* Most of the growth data are limited to the early years of life, because the fish populations in the reclaimed ponds are only a few years old.

METHODS

Age determinations and scale measurements were made on an Eberbach scale projector. Generally accepted procedures for age-and-growth studies by the scale method (Van Oosten, 1929, and Hile, 1941) were followed. Many of the fish examined were of a known age, having been spawned following reclamation of the ponds. Scales from other specimens showed altered growth patterns resulting from increased growth after stocking in their new environment. A direct proportion nomograph, utilizing a correction factor of 1.25 inches for each of the three species was used to calculate past lengths. The use of this linear relationship appears valid because length frequency distributions showed good agreement with cal-

culated body lengths and most of the fishes examined were medium-sized adults adaptable to a straight line body-scale relationship (Rounsefell and Everhart, 1953).

Scale samples were taken from an area beneath the posterior extension of the pectoral fin, below the lateral line. For chain pickerel, which has a ventrally located pectoral fin, scales were taken from the same general body area as the other species. Total length was measured to the nearest tenth of an inch, from the tip of the snout to the very end of the tail with the caudal lobes squeezed together. Most of the fish studied were taken in fyke nets, but some were taken by gill nets, hook and line, and rotenone. Since growth differences due to gear selectivity were found to be small, the samples were combined.

As a basis for comparison, statewide average growth rates for most game and pan fishes common to Massachusetts waters compiled by Stroud (*op. cit.*) were used. These average growth rates were based on the direct aging of 6,361 scale samples collected from measured fish during the 1951 and 1952 reconnaissance survey of 132 ponds. Since these averages represent lengths at time of capture, it was necessary to interpolate the sizes at the end of each year. Some error may possibly have resulted but it is believed that the figures so derived and which are used in this paper are a usable approximation of statewide average growth.

YELLOW PERCH

Growth of yellow perch is generally slower under natural conditions in Massachusetts than in most other waters (Table 1). On the average, about eight years are required for yellow perch to become eight inches long, whereas this length is reached in four years in most other areas. Stroud (*op. cit.*) pointed out, however, that the potential for more rapid growth exists in Massachusetts since growth in three of the ponds he surveyed compared favorably with more rapid growth in other waters.

Growth studies of perch conducted more recently in some reclaimed waters in Massachusetts verify Stroud's conclusion and indicate even greater growth potential than previously shown. In two of five reclaimed ponds, a length of more than eight inches was attained in two years (Table 1). Here, yellow perch reached this desirable size in one-quarter of the time required in many other Massachusetts waters. Such growth is more rapid than any listed by Carlander (1950, and 1953), for most other parts of the country.

Yellow perch stocked after ponds had been renovated showed substantial increases in annual growth. This was also true of perch surviving partial reclamation and population thinning. In Stearns Pond, North Andover, perch were stocked in March of 1954, following reclamation in the fall of 1953. A sample taken in June of 1956 included 76 four-year-

TABLE 1.—*Average calculated total lengths in inches of yellow perch at end of each year of life in five three Massachusetts ponds compared to that in some other waters*

Location	Number of fish	Source	Age						
			I	II	III	IV	V	VI	VII
123 ponds, Massachusetts	1827	Stroud, 1955	2.9	4.8	5.5	5.7	6.0	6.5	7.2
Unweighted mean of 11 references	5026	Carlander, 1953	2.9	5.3	7.1	8.1	9.1	9.8	10.7
Lake Erie	2644	Jobes, 1952	3.7	6.7	8.5	9.5	10.4	11.0	
Claytor Lake, Virginia	59	Roseberry, 1951	3.1	5.5	8.5	9.9			
Reclaimed ponds									
Ezekial Pond	99	This report	4.0	6.2					
Long Pond	49	This report	3.2	6.6					
Curlew Pond	60	This report	5.1	7.5					
White's Pond	146	This report	5.2	8.1	9.5				
Stearn's Pond	33	This report	5.5	8.7	9.2				

old fish which were two-year-olds when stocked in March of 1954. Average annual growth increments for fish of this group were 3.7, 1.9, 3.2 ,and 1.1 inches, respectively, for the first, second, third, and fourth years of life. Thus, in the year after stocking (third year of life), the average annual increment was 60 percent greater than during the previous year. Limited data from other ponds in some cases indicate increases in annual growth of more than 100 percent in the year after stocking.

CHAIN PICKEREL

In Massachusetts, chain pickerel usually attain legal size (14 inches) at the beginning of the fifth year of life. This is somewhat slower growth than average growth in many other waters, where a length of 14 inches is usually reached in three years (Table 2). However, recent growth studies on reclaimed Massachusetts lakes indicate that faster growth rates are possible under improved conditions. In three reclaimed ponds, legal size was attained early in the third year, or almost two years earlier than under average Massachusetts conditions.

Annual growth increments of chain pickerel in Paradise Pond, Princeton, increased substantially during the year following partial reclamation in 1956. For 2-year-old pickerel average growth increase was 55 percent more than that of pre-management 2-year-old fish; for 3-year-old fish, 48 percent more; and for 4-year-old fish, 160 percent more than fish of equivalent age under pre-management conditions.

LARGEMOUTH BASS

Average growth of largemouth bass in Massachusetts is similar to that in most other northern areas of the United States. Legal length in Massachusetts (10 inches) is usually attained at the end of the third year of life.

Limited age-and-growth data from three reclaimed ponds indicate that more rapid growth is possible than is usual in Massachusetts waters (Table 3). In these ponds, largemouth bass attained legal size during their second year and were growing at a rate similar to that in many southern waters, where more rapid growth is often attributed to longer growing seasons.

In Micajah Pond, Plymouth, a reclaimed pond, largemouth bass of mixed sizes (3 to 21 inches) were stocked in 1953. Some of these fish spawned in 1953 and 1954 and created two very large year classes. After their first year of life, fish of these naturally-spawned year classes grew slowly. Average annual increments were 1.4 inches in 1955 and 0.9 inches in 1956. In these same two years, the older largemouth bass which had been stocked in the pond had increments of 2.7 inches and 2.2 inches, respectively. Although growth of the younger fish was very slow, the older fish showed good growth (Table 4). Apparently, the slow growth of the bass of the naturally spawned 1953 and 1954 year classes was due to an overabundance of these small fish and competition for the invertebrate food supply, but the older stocked largemouth bass probably fed mainly on young fish, of which there was an adequate supply to sustain good growth.

DISCUSSION

It is likely that the reported rapid growth of perch, pickerel, and bass in Massachusetts reclaimed waters was the result of decreased competition for food because of low population densities. Better than average growth

TABLE 2.—*Average calculated total length in inches of chain pickerel at end of each year of life in reclaimed Massachusetts ponds compared to that in some other waters*

Location	Number of fish	Source	Age					
			I	II	III	IV	V	VI
Three reclaimed ponds, Massachusetts	145	This report	8.1	13.3	16.7			
120 ponds, Massachusetts	1056	Stroud, 1955	6.7	9.4	11.4	13.9	15.5	17.6
Lakes and ponds, Connecticut	118	Webster, 1942	7.1	11.1	14.0	16.4	18.4	20.4
Lakes and ponds, New Jersey	329	Survey, 1950 N. J. Fisheries	5.5	10.0	14.0	16.5	21.0	24.0

rates have also been noted in new impoundments elsewhere, where lack of competition existed. It appears from the data from these ponds that the rate of growth of yellow perch, chain pickerel, and largemouth bass is more dependent here upon population density than upon length of growing season or other factors effecting growth.

Increases in growth rates following population thinning with rotenone indicate considerable elasticity of growth in these three species of fish. To the fishery manager, this flexibility of growth has important management implications. From an analysis of scales to determine growth, it may be possible to estimate population densities, relative strengths of year classes produced naturally after reclamation and restocking, adequacy of restocking, or, in the case of partial reclamations, whether or not the fish population has been thinned sufficiently. Growth information may therefore be important for determining the need for any additional corrective management after ponds have undergone initial reclamation.

This demonstrated elasticity of growth shows the value of intensive fish population thinning with rotenone, especially in northern areas where growing seasons are short. When conditions for rapid growth are created by thinning, more fish in a fish population can be expected to be of desirable size than in a denser population where growth of all fish is slow. This should mean more desirable fish for the angler to catch and keep.

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TABLE 4.—*Average calculated total lengths in inches of largemouth bass at end of each year of life in Micajah Pond, Plymouth, Massachusetts, by year classes.* [1952 year class stocked after reclamation of pond, 1953 and 1954 year classes spawned in pond]

Year class	Age group	Number of fish	Age I	II	III	IV
1954	II	5	3.1	4.2		
1953	III	12	3.1	4.6	5.4	
1952	IV	9	4.8	8.9	11.6	13.8

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TABLE 3.—*Average calculated total length in inches of largemouth bass at end of each year of life in three reclaimed Massachusetts ponds compared to that in some other waters*

Location	Number of fish	Source	Age I	II	III	IV	V	VI	VII
Three reclaimed ponds, Massachusetts	59	This Report	4.9	10.1	12.6				
59 ponds, Massachusetts	293	Stroud, 1955		7.5	10.0	12.6	14.1		
Median of 30 references	—	Carlander, 1953	4.0	8.2	11.1	13.8	14.9	16.2	17.5
1st quartile of 30 references	—	Carlander, 1953	6.9	10.6	14.0	14.4	16.0	17.3	19.0

Life History Studies of the Spottail Shiner of Clear Lake, Iowa, With Particular Reference to Some Sampling Problems [1]

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ABSTRACT

Collections of spottail shiners, *Notropis budsonius budsonius,* were made by systematic seining in Clear Lake from 1956 to 1958. Spottails made up 4.7 and 8.5 percent of the total number of fish caught in minnow seine hauls during the summers of 1956 and 1957 respectively. For this reason, it is believed that the spottail shiner is not of major importance as a forage fish in Clear Lake. Young of the year comprised 80, 47, and 74 percent of the spottail catch in 1956, 1957, and 1958 respectively. Growth was determined from length frequency and from scale analysis. Scales were formed when the spottails were 18 to 20 millimeters in total length. The body-scale relationship had an intercept of 14 millimeters.

Average daily growth increments of young-of-the-year spottails in the summers of 1956, 1957 and 1958 were 0.52, 0.69 and 0.65 millimeters per day respectively. Higher temperatures were related to faster growth. The growth rate of minnows of the 1956 year class from October, 1956 to June, 1957 was 0.022 millimeters per day and during the second summer was 0.18 millimeters per day. Weighted mean lengths of the spottails at the formation of their first, second, and third annuli, were 76.9, 98.2 and 107.9 millimeters respectively. A subsampling scheme was used in the growth analysis.

The spottails were collected more frequently at locations where moderate amounts of emergent and submergent vegetation were found. Spottails fed on a wide variety of materials which included water mites, Diptera larvae and adults, Tricoptera larvae, Cladocera, grass seeds and plant fibers. A moderate infection of black grub (*Neascus nolfi* and a diplostomum type) was found in only one sample of spottails.

INTRODUCTION

The spottail shiner is a favorite bait minnow for walleye fishing and is an important forage fish in larger midwestern lakes and rivers. Bailey and Harrison (1945) reported that although the spottail shiner once formed large schools in Clear Lake, the commercial taking of these minnows for bait apparently reduced their numbers until the State Conservation Commission passed a law prohibiting seining in the lake. Since then the spottails have increased in numbers, but they are not yet abundant.

MATERIALS AND METHODS

Sampling technique

Spottails for this study were collected in a 30-foot bag seine with one-quarter inch mesh. Cheese cloth was placed in the center of the bag to retain any of the smaller fish that could normally get through the mesh.

In the summers of 1956 and 1957, the seining followed a statistical sampling technique set up in a Latin square design. Twelve stations were picked along the shore of the lake, and once each week for a 12-week period every station was sampled randomly in such a way that each area was sampled once during each 2-hour period during the day.[2] The reced-

[1]Journal Paper No. J-3591 of the Iowa Agricultural and Home Economics Experiment Station, Ames, Iowa. Project No. 1374. Iowa Cooperative Fisheries Research Unit, sponsored by the Iowa State Conservation Commission and Iowa State College with the cooperation of the U. S. Fish and Wildlife Service. Sport Fishing Institute also gave a grant to aid in this study.

[2]Ridenhour, Richard L. 1958. Ecology of young game fishes of Clear Lake, Iowa. Unpublished Ph.D. Thesis. Ames, Iowa. Iowa State College Library. 119 pp.

ing water level and lake modifications made it necessary to move two locations in 1957. Two separate hauls were made at each location during each sampling period.

Analysis of the 1956 and 1957 data indicated that night seining caught more fish of all species. Therefore, the 1958 sampling was done at night using a Latin square design, running for 6 weeks at 6 locations. The 12-hour sampling period (six 2-hour periods) started at 8 p.m. and continued until 6 a.m. the next morning.

All spottail shiners were measured from most seine hauls, but when the numbers were large, only a sample, picked randomly without selection as to size of fish, was measured. Scales for age and growth study were collected from a somewhat smaller sample. Data from a few sporadic samples taken in 1951 were also included in the study.

Scale preparation and reading

Scales were placed between two glass slides bound at the ends with masking tape and examined in a microprojector at 84 diameters. All scales were aged twice without reference to the lengths of the fish. When conflicts existed, the scales were read for a third time using all available data to assist in the aging of the fish.

To avoid reading an extremely large number of scales in 1956, a stratified random sample of scale envelopes was selected. This was done by placing the envelopes for each year into 5 millimeter classes according to the length of the spottail and then taking a random sample of 5 envelopes from each class.

During the examination of the scale samples taken in 1951, it was noticed that the annuli on the yearling spottail scales had not formed by the middle of June, and it was not until the beginning of July that scale samples from spottails taken in 1956 and 1957 began to show the addition of wider circuli on the edge of the scale in the posterior field. The formation of the annuli in the posterior field was followed later by the anastomosis or cutting over of the circuli in the lateral fields.

Length conversion factor

During the summer of 1956, total length, fork length and standard length measurements were recorded to the nearest millimeter for all spottails from which scale samples were taken. To reduce the number of measurements for later samples and to obtain a conversion factor, the following regression of standard to total length was computed using 85 spottails from the 1956 collection:

Standard length = 0.805 total length + 0.08 millimeters

The correlation coefficient was 0.999, which indicated an almost perfect correlation. Since the caudal fin of spottails is often split, fork length measurements were considered less accurate than standard and total lengths and therefore were not treated later.

Body-scale relationship

To determine sizes of fish at the time of previous annulus formation the following linear regression, based upon 85 spottails 28 to 117 millimeters in length collected in 1956, was used.

$$L = 14.2 \text{ mm.} + 0.37R$$

where L = total length in millimeters

and R = scale radius in millimeters (X84)

The correlation coefficient, r, was 0.975.

Length of fry at scale formation

The "a" value or intercept of the body-scale regression line is theoretically equal to the length of the fish when pin point scales are formed, if the body-scale regression line is a straight line over its entire length. Carlander[3] reported that some spottails in the Lake of the Woods, Minnesota, did not develop scales until they were over 23 millimeters long.

Thirty-nine advanced fry caught during the summer of 1951 were examined to determine size at scale formation. These preserved fry were placed in an alizarin red solution for about 12 hours. After rinsing, the skin of each spottail was examined under a dissecting microscope. Spottails of 16 and 17 millimeters total length showed indications of scale pockets, but no scales or bony deposits could be found. Spottails of 18 to 19 millimeters showed a concentration of bony material in the scale pockets which by this time had formed over most of the fish's body. In the more developed spottail shiners of this size group, the bony material had solidified enough that the platelets could be grasped with forceps. The surface

[3]Carlander, Kenneth D. 1943. Growth rate of the spottail minnow, *Notropis hudsonius* (Clinton), in Minnesota waters. Minn. Bur. Fish. Res. Invest Rept. No. 50. typewritten. 3 p.

of the platelet at this state had a pebbled appearance (see Creaser, 1926 and Wallin, 1957). The platelets first began to form at the base of the anal fin, and were found over most of the body before any circuli began to form. On all fish over 18 millimeters, matured platelets or scales were formed, but no circuli were found on scales of fish less than 20 millimeters total length. Within the 25 to 31 millimeter size range, little, if any, relationship existed between size of the spottail and the number of circuli, 3 to 8, on the scale. Although the shape of the scales varied from different regions of the body of a 28 millimeter shiner, all of the scales had from 6 to 7 circuli on them.

If platelet formation takes place when the spottails are from 17 to 19 millimeters long, the pin point start of the scale would probably correspond to a body length of 14 millimeters, the same value as the "a" value derived from the 1956 body-scale regression.

AGE AND GROWTH

Young-of-the-year spottail shiners could be readily recognized by their size distribution, but scale examination was necessary to assign the older spottails to age groups. Scales of 259 spottails, selected at random from each size group in the 1956 collections, were examined in the laboratory and the other fish were assigned to the age groups on the basis of their size (Table 1). In 1957, ages of most fish could be determined from weekly length frequency tables and scales were examined only for those fish in the regions of overlap of the age groups (Table 2)

TABLE 1.—Age group composition by total lengths of the spottails collected from Clear Lake, Iowa, July 4 to September 4, 1956.

Total lengths	From scale examination				Total number of fish taken	Estimate for entire sample			
(mm)	0	I	II	III		0	I	II	III
17-81	78				1041	1041			
82-85	7	8			15	7	8		
86-94		41			91		91		
95-109		54	51		141		73	68	
110-112			3	5	8			3	5
113-117				12	12				12
Total	85	103	64	17	1308	1048	172	71	17
Total percentage						80	13	6	1

TABLE 2.—Age group composition by total lengths of the spottails collected from Clear Lake, Iowa, June 17 to September 5, 1957.

Total lengths	Number	Age of fish			
(mm)	examined[1]	0	I	II	III
13-74	0	720			
75-81	6	15	17		
82-99	64		681		
100-105	99		82	28	
106-109	12			20	
110-111	8			6	2
112-114	2				3
Total	121	735	780	54	5
Total percentage		47	49	3	1

[1]Age could be determined by weekly length frequency graphs for most specimens and scales were examined only for fish which were in the region of overlap of the age groups.

The percentage of young-of-the-year in 1957 was less than that of 1956. The smaller size of the young-of-the-year when seining began in 1957 (Table 3) may have allowed more of the young-of-the-year to pass through the net, therefore causing a lower percentage of them to be caught in 1957. However, it is believed that such losses were small and that the 1957 year class was relatively low in abundance. The 1958 data indicated that the young-of-the-year comprised about 74 percent of the total number of spottails taken in the seine hauls.

Growth rate of the young-of-the-year

During the summers of 1956, 1957 and 1958, the total length measurements of a sample of the young-of-the-year spottails were recorded by weekly intervals (Table 3). These young-of-the-year were distinguished readily on the basis of their size distribution. Mean lengths did not differ significantly among the various stations around the lake.

Hubbs (1921) found that spottail fry in Portage Lake, Michigan grew 0.5 millimeters (standard length) per day for the first month. The average daily increment in Clear Lake was 0.52 millimeters (total length) for the 11-week period ending September 18, 1956, 0.69 millimeters for the 11-week period ending September 3, 1957, and 0.65 millimeters for

TABLE 3.—*Weekly records of total lengths in millimeters of the young-of-the-year spottails in Clear Lake, 1956, 1957 and 1958* [N is number of fish taken in sample]

1956				1957				1958			
Date[1]	N	Mean	Range	Date[1]	N	Mean	Range	Date[1]	N	Mean	Range
				6/18	20	16.6	13-22				
				6/25	30	20.7	13-28				
7/3	13	31.2	24-46	7/2	43	23.6	15-41				
7/10	47	37.9	17-50	7/9	54	29.1	20-42				
7/17	28	38.4	18-47	7/16	18	33.2	28-39				
7/24	33	43.9	21-52	7/23	37	41.1	31-49	7/21	52	36.6	28-47
7/31	60	52.0	31-59	7/30	98	47.0	30-55	7/29	56	39.7	25-53
8/7	50	56.8	45-65	8/6	61	52.7	42-59	8/5	66	44.9	30-62
8/14	70	60.1	53-69	8/13	56	56.5	49-72	8/11	76	51.7	43-68
8/21	59	63.9	56-69	8/20	65	61.1	53-68	8/18	113	55.0	45-68
8/28	172	66.0	58-74	8/27	158	65.4	53-75	8/25	83	59.4	50-70
9/7	41	69.4	60-76	9/3	95	69.4	59-81				
9/18	129	71.6	57-77								
10/27	114	77.4	68-85								

[1]Center date of sampling period for that week.

the 5-week period ending August 25, 1958. Considering only the similar 5-week periods ending in the last week of August in each of the years, the average daily increments were 0.63, 0.68, and 0.65 millimeters per day. However, even these periods were not directly comparable because the sizes of the fish at the start of the period were not the same each year (*see* Larkin, Terpenning and Parker, 1957).

The mean lengths during the week of July 21-27 are a function of time of hatching and of growth rate to that week and appear to be correlated with mean air temperatures for the period May 1 to July 24 in the Clear Lake vicinity (Table 4). The growth during the July 24 to August 28 period also indicates that more rapid growth was associated with higher temperatures. It has been pointed out above that the growth comparisons for this period may not have been entirely valid because of differences in length at the beginning of the period. The younger fish may have had a faster growth rate due to size alone. To avoid this source of error, the rates for similar size spottails were studied (Table 5). In all comparisons (A *vs.* B, C *vs.* E, and D *vs.* E), the faster growth rate was accompanied by a higher average daily temperature.

TABLE 4.—*Mean air temperatures and mean total lengths of spottail shiners at Clear Lake, Iowa*[1]

Mean air temperatures	1956	1957	1958
April	42.1°F.	46.6°F.	46.6°F.
May	58.6	55.8	60.0
June	72.5	66.1	62.7
July 1-24	67.7	75.7	67.4
May 1 to July 24	66.1	65.1	63.0
Mean total length of spottails, July 21-27	43.9 mm.	41.1 mm.	36.6 mm.
Mean air temperature—August	70.0°F.	80.3°F.	73.1°F.
Daily increment of spottails July 24 to August 28	0.63 mm.	0.68 mm.	0.65 mm.

[1]Air temperatures from the U. S. Weather Bureau 1956, 1957, and 1958 are used since water temperatures are not available for this period. Since Clear Lake is shallow and not stratified, the water temperatures are probably closely correlated with air temperatures.

TABLE 5.—*Comparison of the growth rates in millimeters of similar size spottails for different average air temperatures during the summers of 1956, 1957 and 1958*

Code for comparison (See text)	A	B	C	D	E
	7/3-9/7	7/2-9/3	7/9-8/14	7/16-8/20	7/21-8/25
Period covered	1956	1957	1956	1957	1958
Beginning mean length	31.2	23.6	37.9	33.2	36.6
Ending mean length	69.4	69.4	60.1	61.1	59.4
Growth per day	.66	.72	.60	.77	.65
Mean air temperature	67.7°	72.4°	69.9°	73.5°	71.4°

TABLE 6.—*Breakdown of Age Group II into subgroups to obtain corrected mean calculated lengths for this age group in the 1956 data*

Age group	Sub-group	Number in subgroup	Number examined for growth	Mean calculated length at each annulus	
				I	II
II	Slow	28	3	75.0	97.0
	Medium	30	5	73.4	96.0
	Fast	13	3	78.0	99.7
	Simple mean		11	75.1	97.3
	Corrected mean	71		74.9	97.1

Growth of yearling spottail shiners

Since the 1956 year class averaged 77.4 millimeters in October 1956 and 82.5 millimeters on June 17, 1957, the average growth was .022 millimeters per day during that period, with most of that growth probably in the spring. On September 2, 1957, their mean total lengths averaged 96.1, indicating a daily growth of 0.18 millimeters per day during the summer.

Calculated lengths at each annulus

Stratified samples, 5 fish from each 5 millimeter length class, were examined from the 1956 and 1957 collections to determine calculated lengths at each annulus. Since the sampling was from fish collected throughout the summer, an 85 millimeter fish (for example) selected in the sampling might have been a fast-growing I age group fish, if collected in early summer, but a slow-growing individual, if collected in late summer. To ensure proper weighting of the data, the following scheme was followed. Weekly length frequency charts for each age class were examined so that the numbers of slow, medium, and fast growing individuals collected during the year could be determined. A corrected mean was then determined as illustrated in Table 6. None of the corrected means differed from the simple means derived from the samples by more than 1.1 millimeters and therefore this correction is not significant in the present study. In other investigations such a correction might be important, however.

Apparently there has been little difference in the growth rate of spottail shiners in Clear Lake during the years of study (Table 7). Carlander (see footnote 3) reported that in

TABLE 7.—*Corrected mean calculated total lengths in millimeters at each year of life for the spottail shiners of Clear Lake, Iowa*

Year class	Year of capture	Number of fish	Calculated lengths at each annulus		
			I	II	III
1949	1951	5	74.2	100.8	
1950	1951	33	77.3		
1953	1956	17	74.9	98.8	108.0
1954	1956	71	74.9	97.1	
	1957	5	72.5	95.5	107.5
	combined	76	74.7	97.0	
1955	1956	172	81.4		
	1957	54	79.0	99.4	
	combined	226	80.0		
1956	1957	780	75.9		
Combined		1137	76.7	98.2	107.9
Mean annual increment			76.7	22.0	9.8

the Lake of the Woods, the calculated standard lengths of the spottails at the first, second and third annuli were 30, 47 and 62 millimeters respectively. The better growth in Clear Lake was probably due to the warmer water and longer growing season.

REPRODUCTION

On May 9, 1958 several gravid females were taken from the east side of the Sand Bar in Clear Lake. The bottom of the shoal area at the seining site consisted of sand and fine gravel. The eggs of most of these female spottails could be stripped by applying slight pressure. Spottails taken June 20, 1958 from the same location showed no mature eggs, the ovaries being about one-fourth the size of the ripe ovaries and containing clear, irregular, cell-like structures. As the season progressed, the size of the ovaries decreased until only a fine ribbon-like structure remained. Apparently spawning in 1958 occurred in May.

Langlois (1954) reported that ripe spottail females were taken on May 15 along the shoal region of Lake Erie; and that the fry appeared in late June or early July. Fish (1932) reported that the spottail spawns along the shores of Lake Erie and its tributaries in late June and early July.

The ripe females in May contained eggs averaging 0.03 inches in diameter. Ten yearling spottails ranging in size from 70 to 90 millimeters (total length) contained from 100 to 1400 eggs each. Twenty-six females which were at least two years old contained from 1300 to 2600 eggs. Within each age group no correlation between size of female and number of eggs was evident. In all the fish the more mature, yellow-colored eggs were mixed with smaller, whitish-colored eggs; but only the mature eggs were counted.

FOOD HABITS

During the summer of 1956 spottails were collected for a study of food habits. Emphasis was put on the examination of the stomach samples taken from the Bayside and Black Rushes stations because plankton and bottom samples also were taken from these locations. The stomachs were removed under a dissecting microscope (10X power), split lengthwise, and the contents flushed with water from a pipette. The larger organisms were classified and counted at 20X power and a drop of the liquid was examined with a compound microscope to identify the microscopic food organisms. If the stomach contents of the spottails from the same sample were similar in composition, only a small number (5 to 6) of the stomachs were examined. When a large variation was found among the stomach contents of the spottails in the same sample, all or a large percentage of the stomachs were examined.

The information was summarized (Table 8) according to the number of stomachs in which an organism was found. In some instances the number of occurrences did not show the actual importance of the organism as food for the spottails. First, the samples of spottails which had uniform stomach contents were only represented by a small number of samples; and therefore, organisms found in these samples did not receive the correct weighting. Secondly, an organism, such as *Lyngbya,* might occur in a large number of stomachs and yet only comprise a small volume.

In several cases, spottails from a single seine haul showed considerable variation in their feeding. For example, in one of the samples taken, some of the spottails in the sample fed almost entirely on surface organisms, others fed almost entirely on plankton organisms, and still a third group fed almost entirely on bottom organisms. Other workers (Forbes and Richardson, 1920; Adams and Hankinson, 1928) have also reported this mixture of feeding levels in samples of spottails. The spottail schools may extend from the surface of the

TABLE 8.—*Numbers of stomachs in which various food items occurred in 108 spottails from Clear Lake, Iowa, July 3 to August 31, 1956*

Animal		Plant	
Arachnoides	24	Plant	41
Hydracarina	24	Grass seeds	7
Insecta	55	Fiber	14
Unidentified	11	Algae	32
Diptera larvae	29	Chlorophyta	10
Diptera adult	20	*Pandorina* spp.	2
Tricoptera larvae	19	*Pediastrum duplex*	4
Hemiptera	8	*Cosmarium spp.*	7
Cicadellidae	3	Chrysophyta	14
Aphidoidea	7	*Melosira* spp.	5
Coleoptera	3	*Cymbella spp.*	2
Hymenoptera	1	*Synedra* spp.	3
Formicidae	1	*Navicula type*	9
Crustacea	48	Cyanophyta	15
Unidentified	7	*Microcystis spp.*	6
Cladocera (unident.)	3	*Lyngbya* spp.	12
Bosmina sp.	27	Empty stomachs	13
Eurycerus sp.	6		
Eggs?	11		
Ostracod	9		

water to the bottom, with individual spottails feeding on organisms entirely from one level, or more likely, the sample taken by the seine haul was made up of several small schools of spottails which were feeding at the different levels.

It was noted that spottails with nearly empty stomachs had a larger variation of food material in their stomachs than spottails which were well fed. Apparently spottails will select a few types of organisms when their food supply is plentiful but will be less selective when the food supply is limited.

To determine if the food eaten by a particular spottail differed from time to time, stomach and intestinal contents were compared. Although in some cases the contents from the two regions were similar, in many cases the compositions of the stomach and intestinal contents were entirely different. The spottails may have moved from one location to another where different food organisms were available or the food preferences of the spottail may have changed during the period of feeding. Another possibility is that the intestinal contents contained a mixture of parts of several meals which did not digest quickly. This latter possibility is not likely, however, since in some cases the soft parts of the food in the intestinal contents showed no visible digestion and were easier to identify than the stomach contents.

In most cases the young-of-the-year spottails were found to feed on the same organisms as the adults. Boesel (1938) reported no correlation between food taken and the size of the spottail.

At the Black Rushes station, which has a large amount of emergent vegetation, the most important and predominate food organisms during the months of July and August were Hydracarina, Diptera and Tricoptera larvae and Diptera adults. At the Bayside station, where there was no emergent vegetation, the main food organisms during the early summer were Cladocera, with adult insects, grass seed and plant fibers dominating the stomach contents during the month of August. At the Hatchery station, where there were only small amounts of submergent vegetation present and at the Boy Scout Camp station where there were only small patches of rushes, the spottails seemed to feed on almost equal amounts of *Bosmina* and Diptera larvae throughout the summer. From 600 to 1000 *Bosmina* were found in the stomach contents of some spottails which had been feeding entirely on this small Cladoceran.

PARASITES

A gross study of the parasites of the digestive tract and body cavity was conducted concurrently with the examination of the stomach contents. A single, unidentified, adult nematode was found in the intestine of a young-of-the-year spottail (64 millimeters long) taken August 15, 1956 at Bayside.

No parasites were observed in the flesh of the spottails in Clear Lake during the summer of 1956 except in one collection taken in August at the West McIntosh station. Many of the 53 spottails taken from this location were moderately infected with black grubs. The smaller and more dominant cysts were identified as metacercariae of *Neascus nolfi* (Hoffman, 1955); and the less common, larger metacercaria as a diplostomulum type.

Although some parasites may have been overlooked, the infection of spottails in Clear Lake was light compared to that reported by Bangham (1930) and Bangham and Hunter (1940) in other waters.

ECOLOGICAL RELATIONSHIPS

The largest spottail populations were found most frequently in areas with moderate amounts of emergent and submergent vegetation. Some spottails were taken from areas with heavy vegetation but open water was nearby in all cases. Another observation indicated this habitat preference. As summer progressed and heavier vegetation developed, the spottails moved out of some areas. In adjacent locations where vegetation was moderate throughout the summer, a fairly constant population of spottails remained. Other fishery workers (Adams and Hankinson, 1928; Forbes and Richardson, 1920) also reported that spottails prefer areas with moderate amounts of vegetation.

No information was collected in this study that would indicate any preference of spottails for a certain bottom type, since most of the bottom of the shoal area in Clear Lake is composed of sand. Hubbs and Lagler (1949) took spottails over many types of bottom material but always in locations with some vegetation or large boulders nearby.

Analysis of the seining catches indicated that the spottails had a tendency to move into shallower water or were more susceptible to seining at night. Bailey and Harrison (1945)

also found this to be true in their work while Hubbs (1921) found that the spottails moved into deeper water at night.

Several studies have indicated that spottails serve as a forage fish. Surber (1939) reported that spottails were an important forage fish for smallmouth bass in the streams of West Virginia. Ewers (1933) and Rawson (1948) found spottails in the stomach contents of northern pike and white bass respectively.

In 1956 spottails comprised 57.9 percent of the fish (other than game and pan fish) taken by the periodic minnow seining and in 1957 they comprised 24.5 percent. Much of the difference was due to an increase in carp reproduction in 1957, but there was also a decline in the numbers of young spottails. Young yellow bass, yellow perch, bluegills, bullheads and other game and pan fish were much more abundant than the various minnows, however, and they provided most of the forage for larger fish in the lake (see also Bailey and Harrison, 1945).

Hunt and Carbine (1951) in their studies found that spottails competed with young-of-the-year pike and yellow perch for food. The spottails in Clear Lake probably competed with young game fish for food, but because of the relatively small number of spottails found in Clear Lake, the competition was not believed to be serious. Spottails comprised only 4.7 and 8.5 percent of the minnow seine catches in 1956 and 1957 respectively.

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Biology of the Flathead Catfish in Kansas

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ABSTRACT

Flathead catfish (*Pylodictis olivaris*) were collected from the Big Blue River, a highly turbid stream, and the Neosho River, a relatively clear stream, in Kansas, mostly by A. C. electric fishing gear. Flathead catfish comprised 15.1 percent of the number of fish taken from the Big Blue, and 10.5 percent of those from the Neosho. Individuals less than 4.0 inches long (total length) were found in riffles; those 4.0 to 12.0 inches long were generally dispersed in the stream; those 12.0 to 16.0 inches long were associated with cover (logs, brush-piles and rocks) in intermediate depths; and those longer than 16.0 inches were solitary, near large cover (especially logs and down trees) in deeper pools. Examination of 258 stomachs, 69 of which were empty, showed that food of flathead catfish 4.0 inches and shorter was nearly all insect larvae; that of fish 4.1 to 10.0 inches, insect larvae, fishes, and crayfish; and that of larger flathead catfish mostly fish and crayfish. Kinds of food eaten evidently depended on its availability.

Young-of-the-year fish were 2.8 inches long in August in the Big Blue River, and 2.7 inches in the Neosho. Later growth in the Big Blue was faster than in the Neosho and five-year-old fish from these two streams had average total lengths of 24.8 and 17.0 inches, respectively. Length-weight relationship is presented. Male catfish in these streams become sexually mature at 15 to 18 inches long (3 to 5 years) and females matured at 18 to 20 inches (4 to 6 years). Sex ratio was approximately 1:1. Spawning occurred from late June to late July, and 6,900 to 11,300 eggs were found in females 21.0 to 24.0 inches long. The cestode, *Marsipometra,* was a common parasite in the duodenum and nematodes occurred occasionally in the hindgut.

INTRODUCTION

The flathead catfish (*Pylodictis olivaris* Rafinesque) occurs "from South Dakota to Pennsylvania and southward in the Mississippi Valley to the Gulf Coastal Plain and in the Rio Grande to northeastern Mexico" (Moore, 1957, p. 142), and in the Great Lakes Region (Hubbs and Lagler, 1947, p. 72). It is present in the major streams and in many impoundments in Kansas, but is less abundant in small streams than in large rivers, and is usually absent from intermittent streams. In Figure 1 are plotted localities in Kansas from which flathead catfish have been recorded in the literature, and localities where we, and others of the State Biological Survey, have captured the species. Our specimens were obtained from the Big Blue River Basin and the Neosho River (open circles in Figure 1).

The Big Blue River ("B" in Figure 1) and its tributaries drain part of south-central Nebraska and northeastern Kansas, comprising a watershed of 9,600 square miles. The Big Blue proper flows from north to south and enters the Kansas River near Manhattan, Kansas. The Big Blue River is 283 miles in length, with an average gradient of 2.8 feet per mile, and its major tributary, Little Blue River, flows 208 miles with a gradient of 5.3 feet per mile (Minckley, 1959, p. 407). Flow of the Big Blue River at Randolph, Kansas, below the confluence of the Big Blue and Little Blue, averages 1,690 cubic feet per second. In Kansas, the Big Blue ranges from 150 to 300 feet in width and is sand-bottomed, highly turbid (to 14,000 p.p.m. and more), and does not become intermittent. Minckley (*loc. cit.*) described the Big Blue and its tributaries in detail, and listed the fishes occurring in this river basin in Kansas.

The Neosho River ("N" in Figure 1) rises in the Flint Hills of Kansas and flows southeast, leaving the State in the extreme southeast

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corner. The stream drains 6,285 square miles in Kansas and enters the Arkansas River near Muskogee, Oklahoma (Schoewe, 1951, p. 299), flowing 281 miles (Kansas State Board of Agri., 1947, pp. 13, 70). The average gradient of the Neosho, above the mouth of its major tributary, the Cottonwood River, is 15 feet per mile. This gradient lessens rapidly below the mouth of the Cottonwood, averaging 1.35 feet per mile from the junction of the two streams to where the Neosho leaves Kansas (Kansas State Board of Agri., *loc. cit.*). Data furnished by the U. S. Army Corps of Engineers indicate an average rate of flow at Parsons, Kansas of 1,774 c.f.s. for the period

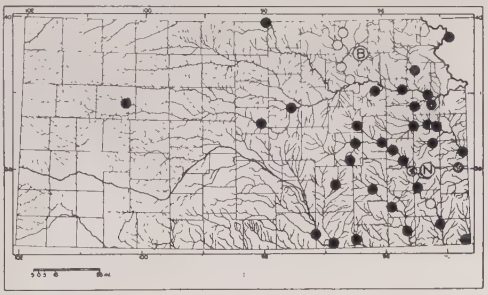

FIGURE 1.—Distribution records of the flathead catfish in Kansas. Open circles are localities where specimens used in this study were obtained; dots are literature records and other recent collection-sites. "B" indicates Big Blue River, "N" indicates Neosho.

October 1956 to September 1957 (maximum—24,900; minimum—0). In the areas where fish were collected for this study, the stream was 75 to 200 feet in width.

The Neosho River has more gravel bottom and is less turbid than the Big Blue River, but the upper two-thirds was at times intermittent during a drought that lasted from 1953 to 1956 in Kansas. A description of two tributaries of the Neosho River System in Kansas, and a list of fishes taken in the streams, has been published by Cross (1954). Hall (1954, pp. 57-60) lists fishes found in the Grand (Neosho) River in Oklahoma.

We studied the ecology of flathead catfish most intensively at one station on the Neosho River, Woodson County, Kansas (hereafter referred to as Neosho Falls). The river in this area flows from northwest to southeast, and is a series of long pools connected by short riffles. Most observations were made on one pool, about one mile in length, 150 feet in width, and eight feet in maximum depth. The bottom was of gravel-rubble, with deposits of mud in deep water and backwater areas. Six cover drifts, composed of one or more large trees, were present, and some limestone slabs provided additional cover along the southwest bank. The southwest side was shallow, from one to three feet in depth, with a gradual slope from the bank to the center of the stream-channel. The northeast bank dropped off abruptly to a depth of three to eight feet. The pool was delimited upstream by a short, swift, turbulent riffle with gravel-rubble bottom, and by a broad, flat riffle downstream. The upstream riffle was apparently the result of a resistant limestone ledge, and averaged about two feet in depth. The downstream riffle had a predominantly gravel bottom and averaged about two and one-half feet in depth. Most fish were obtained by means of a 110-volt, 600-watt, A.C. shocker.

RELATIVE ABUNDANCE

In the Big Blue River, flathead catfish comprised 1.8 percent of all fish taken by combined shocker, rotenone, and seining, and 0.8 percent of all fish taken in the Little Blue River (Minckley, 1959). Of fish taken by the electric shocker alone, which selectively samples the larger elements of the fauna, the species made up 15.1 percent of the total sample from the Big Blue and Little Blue rivers. In the Neosho, the flathead catfish comprised 3.7 percent of all fish taken by shocker, seining, and rotenone, and 10.5 percent of the fish taken by electric shocker alone.

HABITAT AND MOVEMENTS

The flathead catfish is most frequently taken in large streams (Beckman, 1953, p. 69; Cleary, 1956, p. 271; Eddy and Surber, 1947, p. 179; Harlan and Speaker, 1956, p. 112; Hubbs and Lagler, 1947, p. 72; Koster, 1957, p. 78; Trautman, 1957, p. 431; and others). Young flathead catfish are usually found under stones on riffles (Hubbs and Lagler, 1947, p. 72; and Koster, 1957, p. 78).

Funk (1957, p. 43) classified the flathead catfish as a "semi-mobile species" in Missouri streams. He reported that 48.9 percent of tagged flathead catfish that were recaptured were found less than one mile, 72.1 percent less than five miles, 76.7 percent less than ten miles, and 90.7 percent less than 25 miles from the point of tagging. No fish was re-

covered more than 50 miles from the point of release. Scott (1951, p. 33), in attempting to estimate the population of flathead catfish in two short sections of the Coosa River, Alabama, marked 17 fish at one locality and 27 fish at the other, later recording 6 and 21 recaptures, respectively. This high incidence of recapture (32.2 and 77.7 percent) seems to substantiate the findings of Funk (1957) in indicating low mobility of the fish.

Funk (*loc. cit.*) discusses the concept of movement of stream-fish from the aspect of sedentary and mobile species. For the more sedentary fishes, he suggests population pressure as the probable reason for movement, with young fish first remaining near the area of hatching, then moving farther away as competition for food and space becomes more severe. Flathead catfish seem to follow this pattern. Young-of-the-year move or are carried from the place of hatching to swift, rubble-bottomed riffles where they remain until two to four inches in total length. At that size, the young fish become more evenly distributed in the stream; some remain on the original riffles, but more move into pools, deeper riffles, and into almost all other habitats. This random distribution seems the rule in fish ranging from 4 inches to approximately 12 inches in length. We usually found fish measuring 12 to 16 inches in length in association with cover at intermediate depths in the stream, while larger individuals, more than 16 inches long, almost invariably near the more massive logs and drift and usually in or near deep holes in the stream-bed. A drift about ten feet in diameter, or a log 10 to 15 feet in length and greater than a foot in diameter, usually yielded only one flathead catfish more than 16 inches in length, whereas drifts 10 to 40 feet in diameter yielded 2 or 3 large individuals. We never shocked more than three large flathead catfish from one drift at one time.

It is evident that some larger flathead catfish in a population are mobile, for on many occasions when one large fish (exceeding 16 inches) had been removed from beneath a log or drift other large individuals could be taken from the same cover at one- to three-day intervals. In some cases this was probably because of local movements into the vacated area from adjacent drifts. However, where drifts were widely separated, the re-occupation must have been by transient fish. A few large flathead catfish were taken in open water, over shallow sandbars in the Big Blue River, and in areas of the Neosho that did not seem suitable for the fish at the time of capture. These may have been wandering fish that would be present to fill any area that became available.[2]

At Neosho Falls, the collections made with the electric shocker indicated greater movements of flathead catfish at night than in daylight. We obtained 1.72 flathead catfish per hour in daylight (6:30 a.m. to 6:30 p.m.), but 2.77 per hour were captured between 6:30 p.m. and 6:30 a.m. These data were obtained in 10.5 hours of daylight shocking and 23.2 hours at night. That the increased rate of capture at night resulted from increased activity is presumptive, but is supported by other information about habits of this species.

According to Koster (1957, p. 78) and Trautman (1957, p. 431), large flathead catfish often move into shallow areas near swift currents or on to riffles at night. Data from Neosho Falls, accumulated in August, 1958, indicate a dispersal of all size-groups at night (Table 1). Studies at all hours indicated that flathead catfish were most abundant, but averaged smaller, along the shallow southwest bank of the principal pool. On the southwest side, larger specimens were taken in the period from dusk to midnight than at other times. On the deeper northeast side, the largest specimens were taken in daylight and smallest specimens were found at night, indicating movement of larger fish from deep water to other areas at night. Riffle-sampling was inadequate in all but the afternoon period, when flathead catfish were on the average smaller than for any other area or time-period (Table 1).

FOOD HABITS

The flathead catfish is primarily a "bottom-feeder" (Breukelman, 1950, p. 8; Forbes and Richardson, 1920, p. 194). Trautman (1957, p. 431) reported large individuals "with their

[2]When shocked, flathead catfish reacted by moving to the surface with the mouth open and opercles extended, and swam in erratic circles for 30 seconds to 2 or 3 minutes. The fish then slowly sank to the bottom, or recovered and swam away. This behavior is in contrast to that of channel catfish (*Ictalurus punctatus*) and bullheads (*Ictalurus* spp.), which usually stiffened and sank to the bottom where they were easily overlooked. In our opinion, few flathead catfish were overlooked because of the latter type of reaction.

mouths widely open, lying on the bottom and usually beside a log or other object, in water less than 5 feet in depth"; also he reports that fishermen had informed him that smaller fishes "dart into the open mouths of flatheads [when alarmed], to be swallowed immediately." We twice observed the feeding behavior of a 14-inch specimen in an aquarium. The fish lay motionless, except for slight movements of the eyes and opercles, and allowed the food-fish (*Notropis lutrensis*) to draw near, on one occasion touching the barbels. Then, with a short lunge by the catfish, the minnow was eaten.

Many authors list fishes as the major food of flathead catfish (Beckman, 1953, p. 69; Eddy and Surber, 1947, p. 179; Forbes and Richardson, 1920, p. 194; Koster, 1957, p. 78; and others). Other foods that have been listed are crayfish, insect larvae, mollusks, worms, frogs, and "terrestrial animals" (Beckman, 1953, p. 69; and Harlan and Speaker, 1956, p. 113). In Oklahoma, Clemens (1954, p. 78) examined six flathead catfish collected from reservoirs, and ranging from 10.1 to 22.0 inches in length; three of these contained insects—"midges and the burrowing mayfly" —and three contained only unidentified remains of fish.

The stomach of the flathead catfish normally occupies the anterior one-half of the body cavity, filling three-fourths or more of the cavity when full. The pyloris is situated on the left side of the body cavity and the well-defined duodenum extends anteriorly, crossing to the right side beneath the esophagus, and in contact anteriorly with the liver. In front of the stomach, the duodenum terminates, and the thin-walled, convoluted hindgut extends posteriorly along the right side.

TABLE 1.—*Average total lengths in inches of flathead catfish taken in different habitats at different times of day in August, 1958, at Neosho Falls, Kansas*
[Ranges in total length are in parentheses]

Time of day	Shallow southwest side	Riffle	Deeper northeast side
Midnight to dawn	6.4 (1.9-10.2)	.....	7.4 (5.6-9.1)
Dawn to noon	7.0 (2.7-11.6)	.....	16.4 (11.7-19.7)
Noon to dusk	6.8 (2.1-13.2)	5.1 (2.7-15.0)	14.6 (9.9-25.5)
Dusk to midnight	6.4 (3.1-17.0)	15.1 (15.1)	10.4 (7.0-15.1)

The intestinal tract is generally about equal in length to the total length of the fish. The stomach, and the duodenum to a lesser degree, are rugose, but the inside of the hindgut is essentially smooth.

In our study, stomachs of larger flathead catfish were immediately removed, labeled, and preserved in four percent formalin. Stomachs from smaller preserved specimens were dissected from the fish in the laboratory. No regurgitation was noted during collection, or in the case of smaller fish, upon contact with the preservative.

In the laboratory, stomachs were grouped according to the total length of each fish at capture as follows: less than 4.0 inches; 4.1 to 10.0 inches; greater than 10.0 inches. The contents of each stomach were examined at various magnifications under a binocular microscope. Food-items were sorted into taxonomic categories, and the individual items in each category counted. Also, the percent of the total contents that each category comprised was estimated. Food in the intestine was not recorded. Calculations that follow are based only on the stomachs that contained foods; non-food items, such as sand, were not included in percentage estimations.

Of the 120 stomachs from the Big Blue River that were examined, 93 contained food and 96 of the 138 fish from the Neosho River contained food (77.5 and 69.5 percent, respectively). Four fish were collected in April, and the contents of their stomachs were not different from contents of stomachs from fish taken in later months. Also, there seemed to be no measurable differences in the composition of stomach-contents of fish from June, July, and August.

Aquatic insect larvae were the most abundant food item (Table 2). For specimens from the Big Blue River, organisms in the stomachs were identified to genus, if possible. Organisms in stomachs from the Neosho River were identified only to order unless generic identities were immediately obvious. Therefore, in stomachs from the latter stream more genera probably occurred than are listed in Table 2.

Food habits of the different size-classes varied considerably (Figure 2). In the Big Blue River, stomachs of fish less than 4.0 inches long contained principally nymphs and larvae of Ephemeroptera, Trichoptera, and Diptera, both on the basis of frequency of

occurrence and average number of individual food items per stomach containing them (Table 3). Ephemeroptera and Trichoptera made up 54 and 29 percent, respectively, of the estimated volume, whereas the smaller dipterous larvae comprised only 6 percent. The principal families and genera of the three most important orders were as follows: Ephemeroptera—Baetidae (*Isonychia, Centroptilium,* and *Ameletus*) and Heptageneiidae (*Heptagenia*); Trichoptera — Hydropsychidae (*Hydropsyche* and *Cheumatopsyche*); and Diptera—Tendipedidae (*Pentaneura*).

Stomachs from the 4.1- to 10.0-inch size-group contained mostly fish and crayfish (estimated 77 percent). Ephemeroptera, although occurring in 37 percent of the stomachs, made up only five percent of the estimated volume. Ephemeroptera, Trichoptera, and Diptera comprised approximately six percent of the total food, and the remaining 28 percent was of plants, Odonata, Megaloptera, and unidentified animal matter (Table 3). Fishes and decapods identified from stomachs of this size-range were: fishes—Cyprinidae (*Notropis lutrensis* and *Semotilus atromaculatus*); Ictaluridae (*Ictalurus punctatus* and *Pylodictis olivaris*); and Decapoda—Astacidae (*Orconectes nais*).

In flathead catfish measuring more than 10.0 inches in total length from the Big Blue River, fishes occurred in 90 percent of the stomachs that contained food, and comprised 79 percent of the estimated volume. Unidentified animal matter comprised 12 percent volume, and Megaloptera, 3 percent. Plant material made up 4 percent of the total estimated volume and was found in only one stomach. The fishes identified were *Carpiodes carpio, Notropis lutrensis, N. stramineus, Ictalurus punctatus,* and *Noturus flavus.*

Our data from stomachs collected in the Neosho River indicate less difference between the food habits of the size-groups than was found in stomachs of flathead catfish from

TABLE 2.—*Food items found in flathead catfish stomachs from the Big Blue and Neosho rivers, Kansas*
[Identification of an organism from either stream is denoted by appropriate letters, "B" for Big Blue River and "N" for Neosho River]

Food item	Stream	
PLANT	B	N
Filamentous algae	B	
Detritus	B	N
ANIMAL	B	N
Nematoda	B	N
Rhabdita	B	N
Cestoda	B	N
Annelida	B	
Lumbricidae	B	
Lumbricus terrestris	B	
Insecta	B	N
Ephemeroptera	B	N
Ephemeridae	B	N
Hexagenia	B	N
Pentagenia	B	
Potamanthus	B	N
Heptageniidae	B	N
Stenonema	B	N
Heptagenia		N
Baetidae	B	N
Ameletus	B	N
Isonychia	B	N
Ephemerella	B	N
Tricorythodes	B	N
Caenis	B	
Centroptilium	B	N
Odonata	B	N
Aeshnidae	B	
Aeshna constricta	B	
Libellulidae		N
Orthoptera	B	N
Gryllidae	B	
Locustidae		N
Plecoptera	B	N
Perlidae	B	N
Acroneuria		N
Neoperla clymene	B	
Hemiptera		N
Gerridae		N
Metrobates		N
Megaloptera	B	N
Corydalidae	B	N
Corydalus cornutus	B	N
Trichoptera	B	N
Hydropsychidae	B	N
Hydropsyche	B	N
Cheumatopsyche	B	N
Potamyia	B	N
Hydroptilidae	B	
Coleoptera	B	N
Dytiscidae	B	
Laccophilus	B	
Elmidae		N
Diptera	B	N
Simuliidae	B	N
Simulium	B	N
Tendipedidae	B	N
Tendipes	B	
Pentaneura	B	N
Decapoda	B	N
Astacidae	B	N
Orconectes nais	B	N
Pelecypoda	B	
Sphaeriidae	B	
Pisidium	B	
Fishes	B	N
Catostomidae	B	
Carpiodes carpio	B	
Cyprinidae	B	N
Semotilus atromaculatus	B	
Notropis lutrensis	B	N
N. stramineus	B	
N. buchanani		N
Ictaluridae	B	N
Ictalurus punctatus	B	N
Pylodictis olivaris	B	
Noturus flavus	B	
N. nocturnus		N
Centrarchidae		N
Lepomis megalotis		N
Percidae		N
Percina phoxocephala		N
Sciaenidae		N
Aplodinotus grunniens		N
Unidentified animal matter	B	N
INORGANIC	B	N

the Big Blue River (Figure 2). In the specimens measuring less than 4.0 inches, Ephemeroptera, Trichoptera, and Diptera were most important (Table 4), as was the case with fish of this size-group from the Big Blue River (Table 3). However, Ephemeroptera was a more important food-item in the Neosho than in the Big Blue, with a corresponding decrease in the importance of Trichoptera.

Flathead catfish from the Neosho River in the 4.1- to 10.0-inch size-range contained Ephemeroptera as the most important single item (Table 4 and Figure 2). Fishes were second in estimated volume, followed by Trichoptera and Decapoda.

A marked difference between food habits of fish more than 10.0 inches in length from the Neosho River and those from the Big Blue River was apparent from the frequency of occurrence and estimated volumes of fishes, decapods, and aquatic insect larvae in stomachs (Figure 2). Fishes, which made up 79 percent volume in the stomachs from the Big Blue, were largely replaced by decapods in the Neosho; fishes made up 37 percent by volume in the Neosho, and decapods 43 percent (Table 4). Aquatic insect larvae made up 11 percent of the volume in stomachs from the Neosho River, as compared with 3 percent in the Big Blue River. Fishes occurring in stomachs from the Neosho were *Notropis lutrensis, N. buchanani, Noturus nocturnus, Lepomis megalotis, Percina phoxocephala,* and *Aplodinotus grunniens.*

An analysis of periodicity of daily feeding was made on flathead catfish collected in late July and early August, 1958, at Neosho Falls. At summer water temperatures of approximately 85.0° F. digestion of foods by flathead catfish is rapid. Specimens taken on setlines, baited between 11:00 p.m. and 12:00 midnight, and checked between 4:00 and 5:00 a.m. the following day, contained bait-fishes that were approximately two-thirds digested; only the hard-parts and the thorax of minnows remained.

At Neosho Falls, 50 percent of 10 fish captured between 6:30 a.m. and 12:30 p.m. had empty stomachs. In the next period (12:30 to 6:30 p.m.) 37 percent of 27 fish had stomachs without foods. In the next two periods, both at night, 37 percent of 39 fish

TABLE 3.—*Analysis of stomach contents of 93 flat head catfish from the Big Blue River, collected in summers of 1957 and 1958*

Food item	36 fish less than 4.1 inches			30 fish, 4.1 to 10.0 inches			27 fish more than 10.0 inches		
	Percentage of stomachs containing item	Average number of organisms in stomachs containing them	Average estimated volume (in percent)	Percentage of stomachs containing item	Average number of organisms in stomachs containing them	Average estimated volume (in percent)	Percentage of stomachs containing item	Average number of organisms in stomachs containing them	Average estimated volume (in percent)
PLANT	3	—	1	7	—	6	11	—	4
ANIMAL									
Nematoda	—	—	—	3	1.0	tr[1]	—	—	—
Cestoda	—	—	—	—	—	—	3	1.0	tr
Annelida	—	—	—	3	1.0	3	—	—	—
Ephemeroptera	69	5.0	54	37	2.6	5	—	—	—
Odonata	3	1.0	1	10	3.0	7	—	—	—
Orthoptera	3	1.0	tr	—	—	—	—	—	—
Plecoptera	—	—	—	7	1.0	1	—	—	—
Megaloptera	—	—	—	10	1.3	7	4	1.0	3
Trichoptera	58	4.1	29	10	2.0	tr	—	—	—
Coleoptera	3	1.0	1	—	—	—	—	—	—
Diptera	47	1.7	6	3	1.0	tr	—	—	—
Decapoda	—	—	—	17	1.0	17	—	—	—
Pelecypoda	—	—	—	3	1.0	tr	—	—	—
Fishes	3	1.0	3	60	1.5	45	90	2.3	79
Unidentified matter	11	—	5	10	—	8	11	—	12

[1]tr = less than 0.5 percent estimated volume.

(6:30 p.m. to 12:30 a.m.) and 33 percent of 24 fish (12:30 to 6:30 a.m.) were without foods. The average number of organisms (all kinds) per stomach were as follows: 6:30 a.m. to 12:30 p.m., 7.8 organisms; 12:30 to 6:30 p.m., 2.1; 6:30 p.m. to 12:30 a.m., 8.3; and 12:30 to 6:30 a.m., 4.3.

On the basis of percentages of empty stomachs in each period, no trends in feeding are apparent. The high percentage of empty stomachs in the 6:30 a.m. to 12:30 p.m. period may be because of the small sample. On the basis of numbers of food-organisms in stomachs and percentages of empty stomachs, feeding seems to continue throughout the day. However, the numbers of organisms in stomachs containing foods indicate that feeding was most intensive at night and in early morning, with the highest average number of organisms in stomachs taken during the period from 6:30 a. m. to 12:30 p. m.

Biotic conditions in the Big Blue River were similar to those described for the Des Moines River, Iowa, by Bailey and Harrison (1948, pp. 115-116), with a sparse invertebrate fauna, and a lack of rooted aquatic vegetation. Gross examination, with a bobbinet seine, of the sand bottom of the mainstream of the Big Blue River revealed a few burrowing Odonata and Ephemeroptera, and riffle-collecting with the bobbinet seine captured only small numbers of aquatic insect larvae. Decapods were almost absent from the mainstream, but were abundant in some of the rocky tributaries.

Greater numbers of aquatic insect larvae were found in association with stationary drifts and debris in the Big Blue River. This same relationship was noted by Bailey and Harrison (*loc. cit.*) in Iowa, who reported that drifts and other debris, though making up a small portion of the total substrate in a stream, may contribute much of the aquatic invertebrate fauna that is available as food to fishes in that stream.

The Neosho River, with its gravel-rubble bottoms, contrasted sharply with the Big Blue River in abundance of aquatic invertebrates. Ephemeroptera, Trichoptera, and Diptera larvae were present under all stones on the riffles and in the main channel, and decapods were commonly taken. However, as in the Big Blue River, rooted aquatic vegetation was lacking.

The flathead catfish apparently feeds on the organisms that are most available at the time of feeding. Of 75 individual fishes identified from stomachs of flathead catfish from the Big Blue River, 46 (61.3 percent) were *Notropis lutrensis,* and 12 (16.0 percent) were *Ictalurus punctatus.* Minckley (1959, p. 432) recorded these two species as the two most abundant

TABLE 4.—*Analysis of stomach contents of 90 flathead catfish from the Neosho River, collected in summers of 1957 and 1958*

Food item	26 fish less than 4.1 inches			46 fish, 4.1 to 10.0 inches			18 fish more than 10.0 inches		
	Percentage of stomachs containing item	Average number of organisms in stomachs containing them	Average estimated volume (in percent)	Percentage of stomachs containing item	Average number of organisms in stomachs containing them	Average estimated volume (in percent)	Percentage of stomachs containing item	Average number of organisms in stomachs containing them	Average estimated volume (in percent)
PLANT	—	—	—	2	—	tr[1]	—	—	—
ANIMAL									
Nematoda	4	1.0	tr	—	—	—	—	—	—
Cestoda	—	—	—	—	—	—	11	1.0	10
Ephemeroptera	85	3.7	67	54	3.6	39	17	5.3	5
Odonata	4	1.0	3	2	1.0	2	—	—	—
Orthoptera	—	—	—	2	1.0	1	—	—	—
Hemiptera	—	—	—	4	1.0	tr	6	1.0	5
Megaloptera	—	—	—	2	1.0	2	6	1.0	tr
Trichoptera	46	3.3	13	50	7.5	13	6	1.0	tr
Coleoptera	—	—	—	9	1.5	3	—	—	—
Diptera	35	1.7	13	4	1.2	tr	—	—	—
Decapoda	—	—	—	13	1.2	12	44	1.0	43
Fishes	4	1.0	2	33	1.1	26	50	1.1	37
Unidentified matter	4	—	2	13	—	1	—	—	—

[1]tr — less than 0.5 percent estimated volume.

fishes in collections from the Big Blue River in 1957 and 1958 (43.5 and 14.0 percent, respectively, of all fish taken).

It seems that the differences in feeding habits between flathead catfish from these two rivers (Figure 2) is a result of difference in abundance of available foods. Apparently flathead catfish in the Big Blue River began to feed at a smaller size more on fishes because of a paucity of available aquatic invertebrates, but fishes were less common in the diet of the flathead catfish in the Neosho because of the greater availability of larger invertebrates (Decapoda) and a larger number of small food-organisms in that stream. Plant materials occurring in stomachs were usually small twigs or other woody fragments, and probably were fortuitous.

AGE AND GROWTH

A detailed study of growth-rates of the flathead catfish was made by McCoy (1955), on fish from 21 Oklahoma impoundments. He also cites other reports of growth-rates of the flathead catfish in that State. Age and growth of flathead catfish have been recorded in the upper Mississippi River in a report of the Upper Mississippi River Conservation Committee (1946) and by Barnickol and Starrett (1951); in the Kaskaskia River, Illinois by Luce (1933); and in the Salt River, Missouri by Purkett (1958). In Kansas, Cross and Hastings (1956) recorded ages and sizes of a number of flathead catfish from the Kansas River near Lawrence. Also, Schoonover and Thompson (1954), and Greer and Cross (1956) have published the ages and sizes of small samples of flathead catfish from Kansas impoundments.

Spines from 154 flathead catfish were collected from the Big Blue and Neosho rivers during the summers of 1957 and 1958. In addition, young-of-the-year were collected from both streams in 1957 and 1958. Pectoral spines, and dorsal spines in some cases, were removed from the larger fish; small fish were preserved, and examined in the laboratory.

All spines were sectioned at the distal end of the basal notch (Sneed, 1951). The sections were immersed in water, and were examined with a binocular microscope, at several magnifications, by transmitted light. Measurements of the anterior radius of the spine, and of the anterior radius of the last (outside) annulus, were made with an ocular micrometer. The total length at the last annulus was then calculated by direct proportion, on the assumption that the growth of the spine is directly proportional to growth in length of the fish (Jenkins, 1954, p. 12).

The cross-sections showed narrow, translucent bands, separated by broad, opaque bands. The narrow bands were distinct and were interpreted as annuli. Similar findings on spines of flathead catfish were reported by Jenkins (*loc. cit.*). False year-marks were uncommon, and were either indistinct or incompletely circled the lumen.

Marzolf (1955, p. 245) found that in older channel catfish, deterioration of tissues surrounding the lumen partially obliterated the first annulus, but did not prevent accurate aging. Jenkins (1954, p. 11) reported that dorsal spines of flathead catfish show less deterioration of this area. Our findings were similar. Questionable pectoral spines were checked by examination of dorsal spines, if available, or by comparison of the diameter of the lumen with the average diameter of the first annulus in younger fish. We found no appreciable dif-

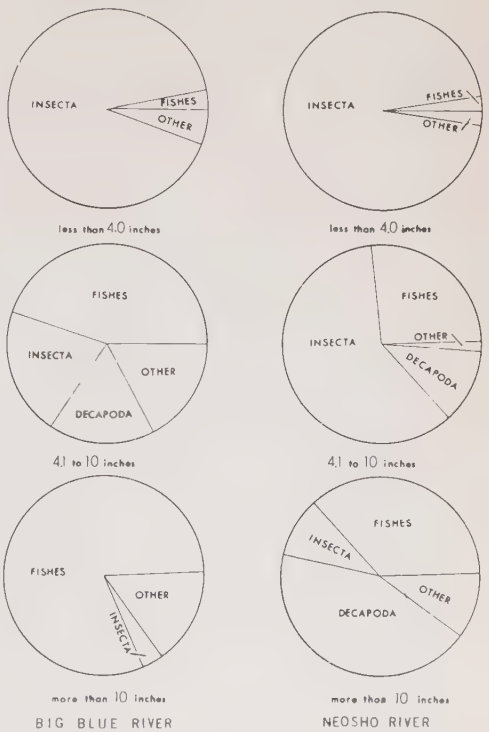

FIGURE 2.—Stomach contents of flathead catfish of different size-groups from the Big Blue and Neosho rivers, Kansas, by estimated percentage volume

ference in growth rates between the sexes.

In the Big Blue River, young-of-the-year were first taken on 29 July, 1957, when they averaged 1.1 inches in total length (range 0.7 to 1.9 inches for 15 fish). On 14 August, 1957, the young that were collected were 1.2 to 4.0 inches in length (average 2.8 inches for 17 fish). Only one series of young were taken in 1958 from the Big Blue River. These were collected in the period 1-10 August, and averaged 1.8 inches in total length (range 1.6 to 2.0, 9 fish). Young-of-the-year flathead catfish were first obtained from the Neosho on 10 July, 1957. These averaged 1.9 inches in length, ranging from 1.6 to 2.2 inches for 6 fish. On 19 August, 1957, 16 young were taken that averaged 2.7 inches (range 1.8 to 4.0). In 1958, young collected in the period 1-10 August, averaged 2.5 inches in length (range 1.9 to 3.0 inches for 25 fish), and specimens from the period 19-20 August, 1958, averaged 3.0 inches (range 2.1 to 4.1 inches for 37 fish).

From the Big Blue River, 75 flathead catfish were aged by examination of spines. Calculated sizes of fish collected in 1957 were not significantly different from fish collected in 1958, and data for both years are combined in Table 5.

Rate of growth of flathead catfish in the Neosha River differed considerably in 1957 and 1958 (Table 5). Flathead catfish from the Neosho averaged 3.1 inches (1957- - Fish) and 3.3 inches (1958 - Fish) less in total length per year than specimens from the Big Blue River. The calculated rate of growth of flathead catfish in the Big Blue River was more rapid throughout life.

The faster growth of flathead catfish in the Big Blue River may be linked with earlier, and more exclusive, utilization of other fishes as food in that stream. Jenkins (1954, p. 13) correlated faster growth of flathead catfish in the Neosho arm of Grand Lake, Oklahoma, with habitat. He found growth faster in areas of "shallow mud flats and relatively turbid water" than in the "clear, rocky" lower part of Grand Lake. Purkett (1958, p. 130) indicated that in Missouri, stream-fishes tend to grow more rapidly in downstream situations in contrast with upstream habitats. In comparing our data with information published by others, it seems that the fastest growth of flathead catfish occurs in turbid, relatively shallow areas, and in the lower parts of streams (Figure 3).

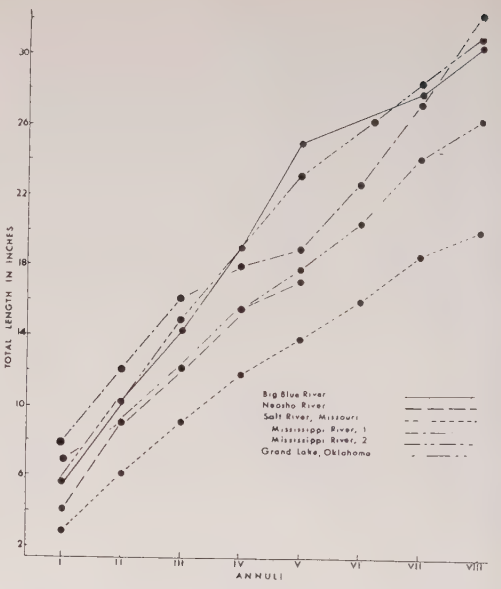

FIGURE 3.—Comparisons of the growth rates of flathead catfish from the Big Blue and Neosho rivers, Kansas, with growth rates from other areas. Growth rates of the 1957- and 1958- fish from the Neosho River were averaged. Lines leading from the edges of dots signify similar growth in the two areas (*i.e.* Neosho River and Mississippi River, 2). Data for Salt River Missouri from Purkett (1958); Mississippi River, 1 [Iowa-Illinois section] and Mississippi River, 2 [Missouri-Illinois section] from Barnickol and Starrett (1951); and for Grand Lake, Oklahoma [Neosho River arm] from Jenkins (1954).

In Figure 3 are plotted the growth-rates of flathead catfish from the Big Blue and Neosho rivers, and growth-rates recorded from other areas. The rate of growth in the Big Blue River, Kansas, corresponds to fastest rates recorded for other streams, and is almost identical to the growth-rate in the Neosho arm of Grand Lake, Oklahoma (Jenkins, 1954). Flathead catfish from the Neosho River grow more slowly than in most other areas, but compare favorably with the Missouri-Illinois section of the Mississippi River (Barnickol and Starrett, 1951).

LENGTH-WEIGHT RELATIONSHIP

Length-weight relationship was calculated for 36 flathead catfish from the Big Blue River and 26 from the Neosho. These fish were collected in late July and early August, 1957. Weights were taken to the nearest 0.5 ounce, and fish were grouped into two-inch size-intervals.

The length-weight relationship of flathead catfish from the Neosho River was similar to that from the Big Blue River. The relationship for fish from both streams is described by the formula Log W = — 5.3873 + 3.0990 Log L. The combined data from both streams are presented in Figure 4.

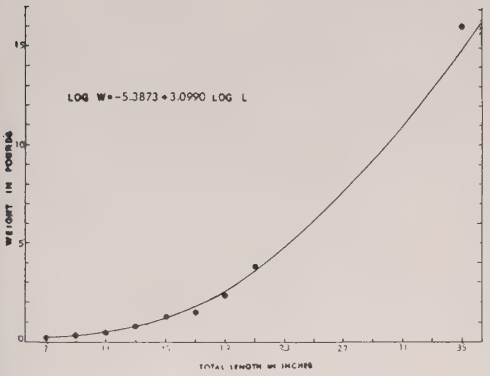

FIGURE 4.—Length-weight relationship of flathead catfish from the Big Blue and Neosho rivers, Kansas. The numbers that indicate lengths are the mean of each length-group (*i.e.* "7" denotes the range 6.0 to 7.9, "9" denotes the range 8.0 to 9.9, and *etc.*). The formula given above describes the theoretical length-weight relationship, and dots are absolute values for our fish.

REPRODUCTION

Of the 212 fish from the Big Blue and Neosho rivers that were sexed, 108 were males and 104 were females, giving a sex ratio of about 1:1. No deviation from this sex ratio was apparent in the different size-groups.

Beckman (1953, p. 69) reported that flathead catfish become sexually mature in their fourth summer of life. In the upper Mississippi River, Barnickol and Starrett (1951, p. 308) found that flathead catfish mature at lengths of 17.0 to 19.0 inches (four or five years of age), and stated (p. 307) "a few mature female flathead catfish less than 15 inches total length were noted; however, the majority of mature females were 18 inches or more in length."

In the Big Blue and Neosho rivers, sexual maturity was attained by males at length of 15.0 to 18.0 inches (average, approximately 17.0 inches), and at an age of 3 or 4 years in the Big Blue, and 4 or 5 years in the Neosho River (Table 5). Females were usually mature at 18.0 to 20.0 inches, as determined largely by examination of spent fish in July. These spent fish were characterized by slack, heavily veined ovaries. Females in the Big Blue River were mature at 4 or 5 years of age, and in the Neosho at 5 or 6 years (Table 5). Our observations indicate that loss of the light-colored patch at the tip of the upper lobe of the caudal fin may indicate sexual maturity.

Estimates were made of the number of ova from the following three mature female flathead catfish taken from the Big Blue River: 28 May, 1957 (24.0 inches total length); 26 June, 1957 (23.0 inches); and 12 June, 1958 (21.0 inches). The number of ova per fish were determined by water displacement (Lagler, 1952, p. 80) and were, respectively 11,300, 6,900, and 9,300. The average diameter of ova from the three fish (measured with an ocular micrometer) were, respectively, 2.84 mm (range 2.56 to 3.20 mm); 2.85 mm (2.56 to 3.04 mm); and 3.22 mm (3.04 to 3.44 mm).

The dates for spawning of flathead catfish are recorded as "May or later" in Illinois (Forbes and Richardson, 1920, p. 194), "spring and early summer" (Koster, 1957, p. 78), and "June and July" (Beckman, 1953, p. 69). In our streams, spawning occurred in late June (Neosho River) and mid-July (Big Blue River) in 1957, and in early July and late July, respectively, in 1958.

PARASITES

Twenty-seven of the 57 fish examined for parasites contained cestodes (average 5.2 per fish; range 1-31). Of the 141 cestodes counted, 90 percent (127 specimens) were in the duodenal region of the intestine. Ten percent were in the hindgut, but were usually in the anterior half. Cestodes were also found in the stomach (Tables 3 and 4), but were in the pyloric region where they could have entered upon contact with the preservative, or could have been displaced by handling of the viscera. Dr. Ralph V. Bangham (*personal communication*) reported that "most appear to be the cestode, *Marsipometra* sp."

Only three fish contained nematodes (unidentified) and 14 specimens were obtained.

TABLE 5.—*Calculated total lengths in inches at the last annulus for flathead catfish from the Big Blue and Neosho rivers, Kansas*

	ANNULI							
	I	II	III	IV	V	VI	VII	VIII
Big Blue River (1957 and 1958 combined)								
Average	5.6	10.3	14.4	19.0	24.8	.....	27.6	30.4
Range	4.2-7.6	8.2-13.0	13.2-16.2	17.0-21.9	20.8-26.5	.....	27.6	30.4
Number of fish	30	19	6	13	5	0	1	1
Neosho River (1957 above, 1958 below)								
Average	4.8	9.5	11.4	15.8	16.5	.....	.....	.....
Range	3.7-5.3	7.2-11.1	11.4	13.5-16.4	16.5	.....	.....	.....
No. of fish	13	8	1	4	1	0	0	0
Average	3.2	8.7	12.8	14.9	17.5	.....	.....	.....
Range	2.0-4.3	7.8-9.8	12.1-13.9	13.7-16.0	16.4-18.4	.....	.....	.....
Number of fish	22	18	5	4	3	0	0	0

Thirteen of these were in the posterior two-thirds of the hindgut, and one was in the pyloric region of the stomach.

ACKNOWLEDGMENTS

The data presented were obtained during fish surveys of the State Biological Survey of Kansas and the Kansas Forestry, Fish, and Game Commission, and were directed by Dr. Frank B. Cross. We wish to thank D. A. Distler, Claude Hastings, D. L. Hoyt, F. E. Maendele, and B. C. Nelson for assistance in the field; the many landowners who allowed access to streams (especially Mr. Floyd Meats); and Dr. Merle Hansen, Kansas State College, who arranged for identification of parasites by Dr. Ralph V. Bangham of Wooster College.

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Shorter Papers and Notes

A Simple Method for Increasing Contrast in Scale Reading

Determination of age and growth of fish by examination of annuli on their scales is commonplace today. Some studies require preparation of slides or impressions, and their use to obtain precise measurements for growth studies. For such studies special methods and equipment are necessary. Many studies, such as the determination of age frequency, require nothing more than the enumeration of annuli. If the latter is the case there is no necessity for complicated or expensive equipment; simple laboratory apparatus is sufficient.

The binocular dissecting microscope as commonly used does not provide the sharp contrast essential for this exacting task. Various authors in the past have described the use of polarized light for improving contrast for scale reading, but such methods require special apparatus. The method described here utilizes equipment usually available in most laboratories. It provides high contrast between circuli and the grooves between them, thereby tending to make the individual circuli stand out sharply. Following is a diagram illustrating the method of aligning this equipment. (See Figure 1).

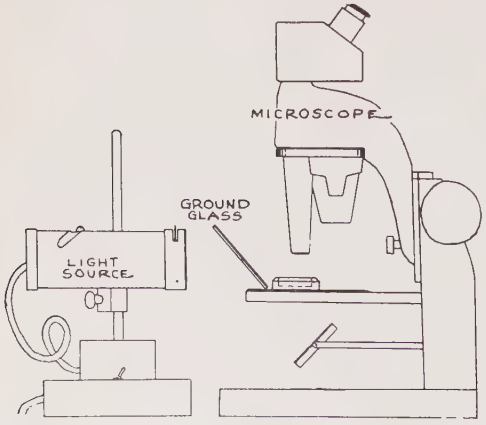

FIGURE 1.—*Alignment of scale reading equipment.*

The watch glass contains a small amount of water and the scales to be aged. Thick scales should be soaked and cleaned. Addition of the ground glass between the light source and the watch glass, and projecting the light horizontally, provide the means of obtaining the high contrast. Another essential is that the microscope stage, immediately beneath the base of the frosted glass, must be clear glass. The angle at which the ground glass is installed is not critical, because the combination of ground glass and mirror must be adjusted to complement each other. Frosted glass can be easily produced by rubbing valve grinding compound on ordinary glass. If the edges of the watch glass are beveled and ground to a frosted surface, the frosted glass between the light and the watch glass may be omitted.

Placing the frosted glass between the lamp and the object as described reduces the light and diffuses it. An ordinary inside-frosted incandescent bulb may be used as a light source if a microscope lamp is not available. A frosted bulb of 60 to 100 watts produces light of about the right intensity and sufficiently diffuse to serve as an acceptable substitute. Any combination of light source and diffuser may be employed, although certain combinations appear to be slightly better. If a frosted light bulb is used, it is desirable to place a shield between the light and the microscope and allow light to fall only on the mirror.

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Movement of Tagged Halibut off New England

Tagging of halibut, *Hippoglossus hippoglossus* (L.), for migration studies is difficult because this fish is rarely found in concentrations and because halibut are very valuable in United States and Canadian markets. Both of these considerations make tagging from commercial vessels or on special trips of research vessels prohibitively expensive. However, during the 1956 meeting of the International Commission for the Northwest Atlantic Fisheries, the Committee on Research and Statistics recommended that member nations carry out marking experiments on halibut whenever and wherever possible.

Since that time, we have been able to tag and release 190 halibut (Table 1). They were captured by Bureau of Commercial Fisheries research vessels primarily engaged in tagging trips for other groundfish species in and around the New England area.

The fish tagged on Cashes Ledge in 1956 and on Georges Bank in April 1957, were marked with Lea tags anchored internally as described by Wise (1958). The rest were tagged with Petersen discs on stainless steel wire or pins inserted through the dorsal muscles.

Seventeen marked halibut have been recaptured. Most of them had not travelled far from the tagging areas. Four, tagged on Cashes Ledge in 1956, were at large a maximum of 55 weeks and were recaptured within 30 miles of the tagging area. Five fish which were tagged on Browns Bank in March 1957, at large up to 65 weeks, and three tagged on Browns in October 1957 at large up to 28 weeks, also were recaptured within 30 miles. One fish, tagged on Grand Manan Banks in November 1957, was recaptured 33 weeks later, but had also travelled less than 30 miles. A halibut recaptured in May 1958 on Grand Manan had lost the numbered disc but we believe he had been tagged there in October or November 1957. One tagged on Jeffreys Ledge in April 1958 was caught 46 miles almost due north at Seguin Island, Maine, four weeks later.

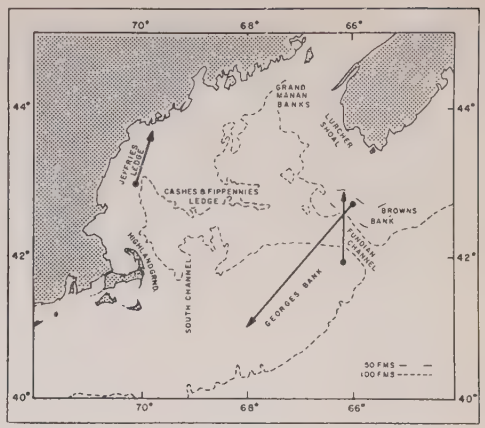

FIGURE 1.—Halibut tagging areas off New England and the movements of the three fish which travelled more than 30 miles.

Two halibut, however, travelled greater distances from where they were tagged. One, tagged on Browns Bank in March 1957, was recaptured eight weeks later and 100 miles away on central Georges Bank. The other, tagged on Georges in April 1957, was recaptured 17 weeks later 60 miles away on northern Browns (Figure 1). Both of these fish were well above the average size (about 50 centimeters) of the series of fish tagged; one

TABLE 1.—*Summary of halibut tagging in New England area 1956-1958*

Date	Location	Number tagged	Length in centimeters
1956			
June-July	Cashes Ledge (42° 50′ N, 68° 55′ W)	13[1]	Under 60
1957			
March	Browns Bank (42° 50′ N, 66° 00′ W)	78	24-99 (mostly 40-60)
April	Georges Bank (41° 55′ N, 66° 10′ W)	1	144
October	South Channel (41° 30′ N, 69° 20′ W)	2	ca. 50
	Browns Bank (42° 50′ N, 66° 00′ W)	68	25-72 (mostly 35-55)
	Lurcher Shoal (43° 45′ N, 66° 28′ W)	2	38, 68
October-November	Grand Manan Banks (44° 10′ N, 67° 00′ W)	13	36-73 (mostly 36-60)
November	Cashes Ledge (42° 55′ N, 68° 55′ W)	2	56, 120
	Fipennies Ledge (42° 48′ N, 69° 20′ W)	1	57
1958			
March	Browns Bank (42° 40′ N, 66° 09′ W)	5	40-60
April	Jeffreys Ledge (42° 54′ N, 70° 10′ W)	3	41-52
November	Highland Grounds (42° 10′ N, 70° 10′ W)	2	51, 67

[1]These fish captured by trawl line; all others by otter trawl.

was 144 centimeters at tagging, the other 71 centimeters. Martin and McCracken (1950) also found that the smaller halibut appear to move less than the larger fish.

Martin and McCracken's observations that halibut do not cross deep-water channels in their travels are not borne out because both of the large halibut crossed the Fundian Channel which is deeper than 100 fathoms. It is barely possible that the fish followed the coast line to go from one bank to the other. However, the great distances involved in a coastwise movement make it unlikely that anything but a direct crossing of the channel occurred in so short a time. Tåning (1938) has shown that migrations across deep water do occur.

Although a comparison of the two types of tags cannot be certainly made because of the small numbers of returns and the varying methods of capture for tagging, difference in return is suggestive. Lea tags were used on only about 7 percent of the fish but they accounted for nearly a quarter of the returns—a difference in proportion of return more than threefold that of the Petersen tags.

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Errata

Paper of Max Katz, Austin Pritchard and Charles E. Warren entitled *Ability of some Salmonids and a Centrarchid to Swim in Water of Reduced Oxygen Content,* Volume 88, Number 2, pp. 88 to 95.

Page 90, Table 1. All column headings and tabular material should be in Table 2. This includes all of the material from the column heading "Date of experiment" until the last numeral "5" in the last line of the table. *Note*: The footnotes 1, 2, 3, listed under the published table 1 are correct and should not be transferred. Page 91, Table 2. All column headings and tabular material in this table should be transferred to Table 1. This includes all of the material from and including the column heading "Date of experiment" until the numeral and superscript "6[3]" in the last line of the table. *Note*: The footnotes 1, 2, 3, and 4 listed under the published Table 2 are correct and should not be transferred.

Page 91, Table 2, footnote 4, line 2. "tn" should read "than". Page 92, Column 2, first paragraph under Coho salmon, line 6, "203" should read "2.03".

The *Note* by L. M. Dickie entitled *"Water Temperature and Survival of Giant Scallop"* which was published in Tran. Am. Fish. Soc. *88*(1), p. 73, was submitted to the editor for publication as an *abstract* of a paper presented orally to the Panel on Marine Fisheries held during the 88th Annual Meeting at Philadelphia. This abstract was submitted under the full title "Effects of Temperature on Survival and Distribution of the Giant Scallop." The papers upon which the oral presentation and abstract are based are being published elsewhere. One of them has appeared in Volume 12 and one in Volume 15 of the J. Fish. Res. Bd. Canada.

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